

SR-01

Production Report

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Introduction.

SR-01 is the first Nb₃Sn subscale racetrack magnet build at Fermilab using PIT conductor and wind and react technology. It is similar in design to LBNL sub-scale coil, but utilized a conductor of approximately double width. As a result, the aluminum cylinder and iron yoke are identical to LBNL design, but in FNAL design only one two-layer racetrack coil is featured (see Fig 1 and Table 1).

The goal for such a device is testing presumably stable PIT cable in a magnet-like configuration. It should be noted that a learning process was part of this production cycle.

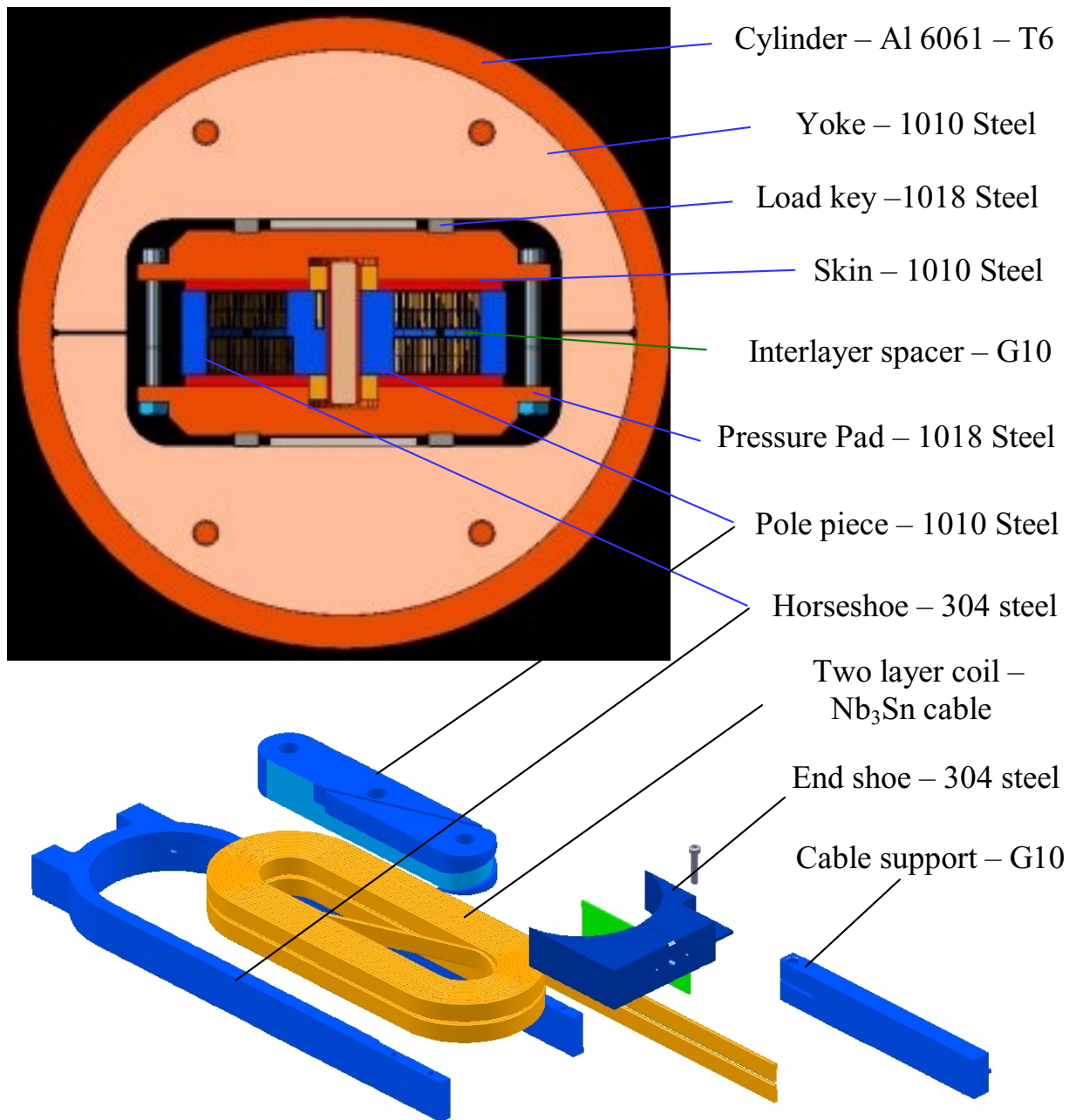


Figure 1. Small Racetrack Magnet.

Table 1. Magnet design parameters.

Magnet parameters

B_{\max} , T	11.06
I_{\max} , kA	28.12
Aperture, mm	2
Coil area, cm ²	6.05
Number of turns per coil	13
Iron yoke OD, mm	215
Stored energy @ 11 T, kJ/m	19.05
Inductance @ 11 T, mH/m	0.05

Cable characteristics

Material	Nb ₃ Sn PIT
Cable type	Rutherford
Dimensions, mm ²	14.20 x 1.84
Strand diameter, mm	1.0
Number of strands	28
Strand Jc (12 T 4.2 K)	2000
Cu/Non_Cu	0.85

Cable Production and Test Data.

FNAL Cable Production and Test Facility produced and tested a compacted cable for the coil using Nb₃Sn PIT strands. Strands and cable specifications are listed below.

CABLE No.	HFDA_030609_28-2
CHARACTERISTICS	1mm PIT - 28 strands
FINISHED	08/06/03
OPERATOR	Tom Wokas

CABLE AND STRANDS LOG SHEET

- STRAND SPECS-

MANUFACTURER :	ShapeMetal Innovation
PROCESS METHOD :	PIT
BILLET #:	170, 171, 172, 173
COMPOSITION :	Nb ₃ Sn
NOMINAL STRAND DIAMETER :	1.0mm
NOMINAL COPPER CONTENT :	53.6%
NOMINAL RRR	-
FILAMENT DIAMETER	34μm
FILAMENT PITCH AND DIRECTION:	20mm, right
RECOMMENDED HEAT TREATMENT	170 hr @ 655°C
I_c and N-VALUE @ 12T	B _# 172 696A 45
	B _# 173 728A 53

NOTES:

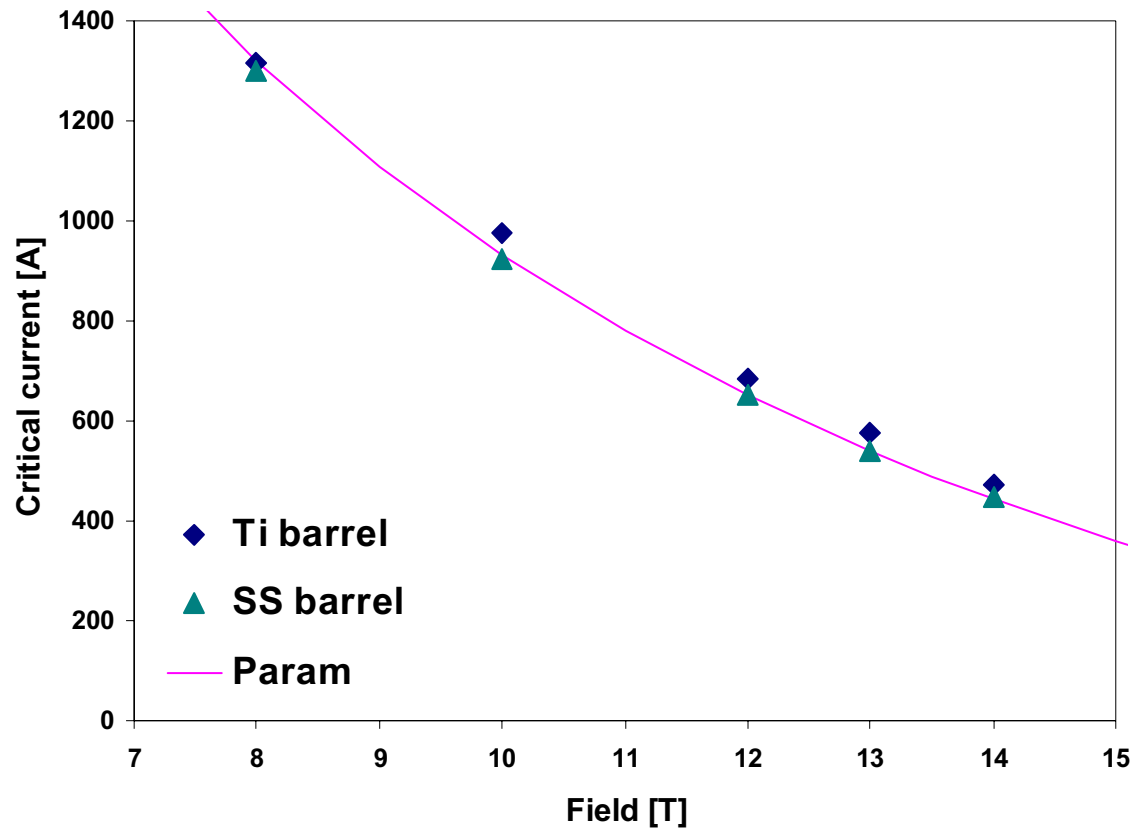
With a heat treatment of 100hr @ 675°C the manufacturer found the following values of I_c and n-value:
B_#170, 665A, 64; B_#172, 652 A, 54; B_#173, 677 A, 44.

-FNAL STRAND DATA-

HEAT TREATMENT			25°C/hr to 660°C; 170 hr @ 660°C			
SHORT SAMPLE DATA OF WITNESS SAMPLES FOR SR-01						
BILLET & SAMPLE #:	TYPE	I _c & N @12T	RRR	BARREL	DATE	BY
170, 1	VIRGIN	686A 50*-95*	80	Ti-alloy	12-05-2003	B. BORDINI
171, 1	VIRGIN	652A 60-64	-	SS	12-12-2003	B. BORDINI

NOTES: Witness samples tested on SS barrels are deemed to be more representative of actual magnet performance since the differential thermal contraction between Nb₃Sn and SS is smaller than between Nb₃Sn and Ti-alloy. For a current of 1000 A at 4.2K, the Nb₃Sn composite is subject to a total tensile strain of ~ +0.05%. This strain variation increases J_c by about 3 to 5 % for a range of intrinsic compressive strain of 0.25 to 0.4%[1].

1 mm PIT 170 series - Round witnesses



-CABLING SPECIFICATIONS-

TYPE or SPEC.:	-						
REALIZED @	FNAL						
No. of STRANDS:	28						
PITCH DIRECTION:	Left	PITCH LENGTH:	110 mm				
PLANETARY RATIO:	1:1						
ROLLER ID #:	Original forming fixture	WIDTH:	Nominal	ANGLE:	0 degree		
MANDREL ID #:	5525-MB-414004	WIDTH:	13.36 mm	THICKNESS:	<u>0.30 mm</u>		
LUBRICATION :	Oil G.P.						
STRAND TENSION:	4 pound	TURKS HEAD LOAD "SGM":	-				
Nom. THICKNESS:	1.84mm						
Nom. WIDTH:	14.2 +/- 0.1 mm						
Nom. ANGLE:	0						
CORE:	No	MATERIAL:	-	THICKNESS:	-	WIDTH:	-

-FINISHED CABLE-

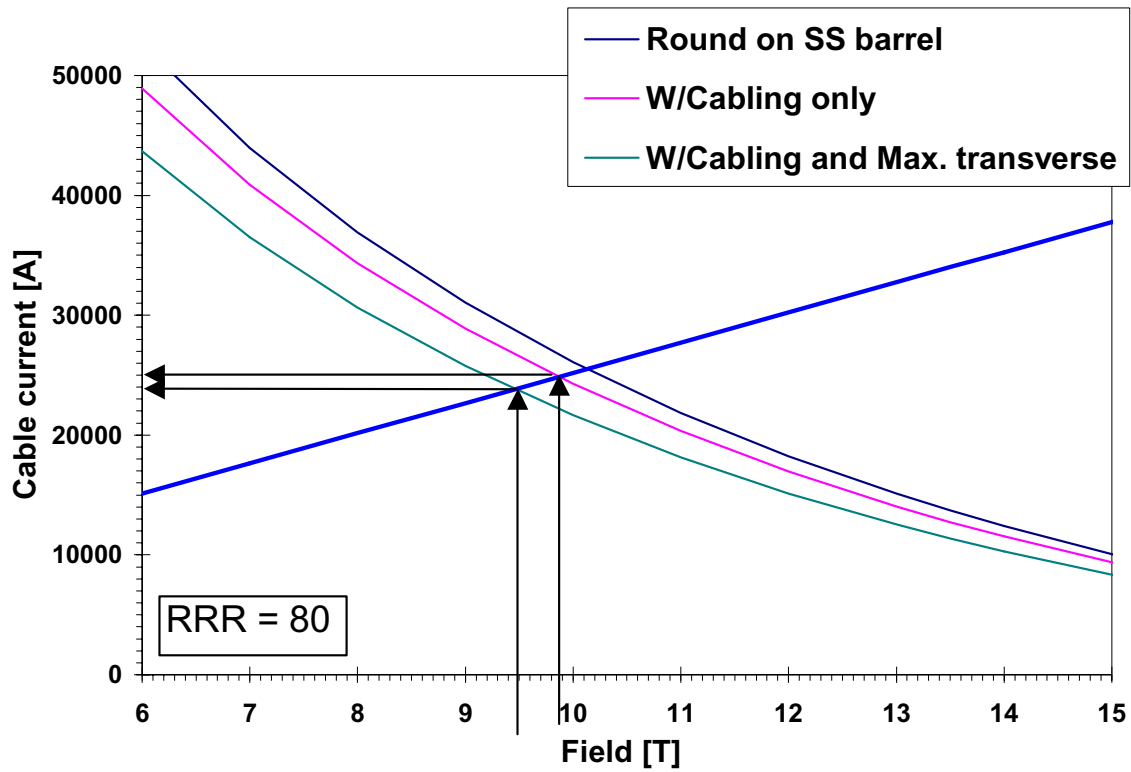
	HFDA_030609_28-2
FINISHED LENGTH:	14.5 m
Avg. THICKNESS:	1.84 mm
Avg. WIDTH:	14.20 mm
Avg. ANGLE:	0 degree
Cable/Strand Yield:	-

RESIDUAL TWIST/Mtr.: _____ -
ETCH for FILAMENT DAMAGE: _____ -

NOTES :

For the first 2-3 m the thickness is 1.8 mm.

Small Racetrack Short Sample Limits



NOTES: Cabling degradation was assumed to be 7% based on previous statistics on PIT strands of similar design. A 10% maximum degradation due to transverse pressure was used based on actual measurements on cable samples and in the assumption of a 40 MPa maximum load on the coil during operation.

Cable Preparation.

The Nb₃Sn cable was heat-treated at 200°C for 30 min (annealing process) to reduce the residual twist that comes from the cabling process.



Figure 2. Spool of cable is packed in Kapton bag before annealing.

Coil Size.

To obtain an acceptable coil dimension, the size of bare and insulated cables was measured at different transfer pressures. Then the required reaction shim thickness was calculated based on the insulated cable data at ~14MPa of pressure and on the dimensions of the other parts.

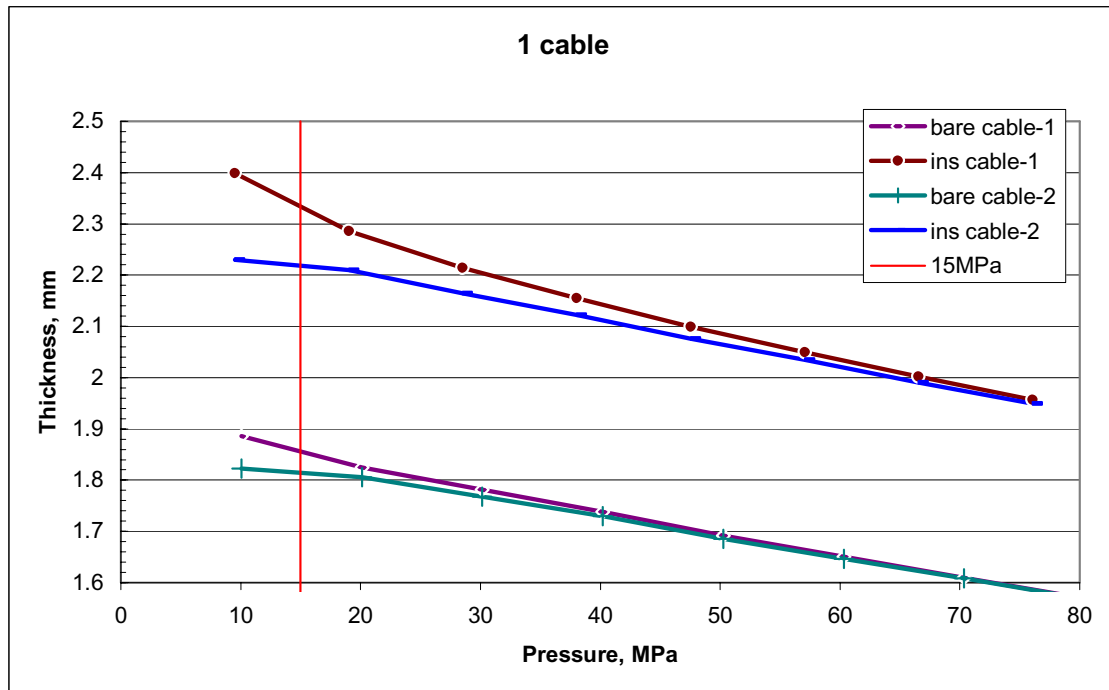


Figure 3. Result of two-cable stack measurements

Table 2. Coil Size Spreadsheet.

FNAL Coil Number		#1 with PIT compacted cable		
Coil Package Components	Nominal Size in mm	Number of Components Turns	Total	Actual Size in mm
Insulated Conductor @ 2ksi equivalent	2.33	13	30.29	60.58
Mica Paper or ceramic (Island only)	0.14	2	0.28	0.28
Island / Plasma Spray	37.8	1	37.8	37.8
Horseshoe Width	9.56	2	19.12	19.12
Total (Line 10 - 13)	49.83			117.78
Reaction Real Width	25.52	2	51.04	51.04
Coil With Horseshoe (15 + 17)				168.82
Plate	170.18	1	170.18	170.18
Glass Overhang	0	2	0	0
Effective Plate Size (22 + 23)				170.18
Difference (19 - 25)				1.36
Positive Number means large coil				
Shim Size mm / per side	168.82	+	Line26/2	0.68
Shim Size inch / per side				0.02677
Shim Size is (1.895) or 0.075" Maximum!				
If bigger try another turn				

Data

Calculation

Sum

Real shim is: 10mil metal+2x4.5=9mil Mica tape+2x6=12mil S-2 glass tape; total=31mil

The “real” shim size corresponds to third attempt of horseshoe installation (see Fig.16).

Cable Insulation.

S-2 Fiberglass Tape 250 μm thick \times 12.95 mm wide has been used for Nb_3Sn cable insulation. The inorganic binder is first applied to a roll of insulation and then cured at 80°C for 30 min. This step improves the stiffness of the insulation. Then the cable was wrapped by a tape with $\sim 3.3\text{mm}$ overlap using an insulating machine in IB3.

The insulated cable size was measured with a micrometer at several points along the piece length. Results are listed below in mm.:

Bare Cable thickness is 1.84mm(compact)
Insulated cable thickness is 2.29mm (1.84+0.45)

Insulation is 0.125mm S-2 glass tape cured with binder : with 3.0mm overlap

Cable parameters	width	thickness	Total cable L=47.5'=14,478m
measured by mic	14.202	1.877	
w/o pressure	14.13	1.887	
after annealing	14.204	1.889	
	14.208	1.887	
	14.18	1.886	
	14.1848	1.8852	

Table 3. Size of Nb_3Sn cable.

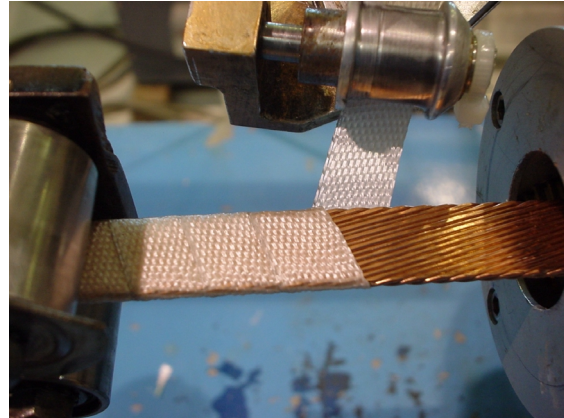


Figure 4. Cable insulation process.

Ground Insulation.

Two types of ground insulation have been used in the process. One is a technological layer of ceramic cloth for cable heat treatment. This cloth covered the side plates of the reaction fixture and provided tiny channels for the Argon flow purging the coils. The second type is a “0-shape” cloth of S-2 Fiberglass material that covered the coils only during the epoxy impregnation step. After curing it forming one of two layers of designed G10 insulation (2x10mil).

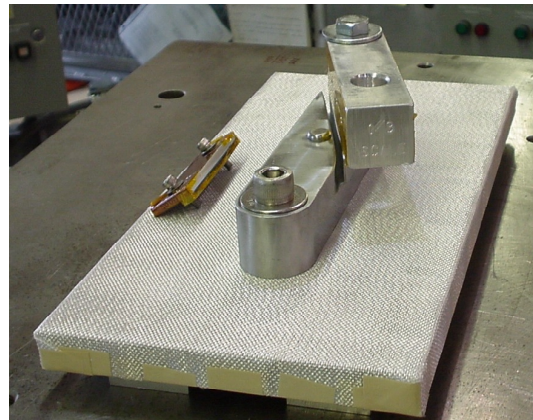


Figure 5. Winding plate (part of the reaction fixture) with ceramic insulation and a pole.

Winding Procedure

1. Perform the Stack process and enter the numbers into the XL Spreadsheet (see Coil Size)
2. Measure all tooling and fill out the Coil Size Spreadsheet
3. Split the cable. Use leader material if the cable is too short. Wind 14.5 meters of usable cable onto a plastic spool.

The insulated cable was re-spoiled under 20 lbs of tension onto two plastic reels, an inner cable reel with 23 feet (7 m) plus 10 feet of copper leader, and an outer cable reel with 23 feet (7 m) plus 10 feet of leader. Starting from the middle point, the cable was pre-deformed around the pole piece to fit into the layer jump groove without strands popping out. The pole was wrapped by ceramic cloth and the cable placed in a slot and held with a clamp. Then 40 lbs of tension was applied to the cable and the first turn was wound. Next

12 turns were wound with 60lbs of tension.



Figure 6. Winding set up.

4. Coat all threaded holes in the reaction fixture with boron nitride.
5. Boron nitride coat all 3/8" reaction nuts and studs again.
6. Coat one winding plate with 10-mil ceramic sheet. Punch out the three 1/2" holes.
7. Install the plate onto the winding table. Use a spacer on the bottom.
8. Install the island (pole) clamping fixture and the spool holding fixture. Bolt down. The ramp section of the island is on the lead end. This matches with the notched end of the winding plates.
9. Place the spool for the 2nd layer-of conductor on the holding fixture.
10. Hook up the multi meter and concomitantly check for shorts to the tooling.
11. Wrap the island contact area of the cable with a half lap of glass tape. Verify that the tape has been oven cleaned. Leave it long so it will come up and protect the cable in the clamp area of the island fixture. This provides extra insulation for the ramp edges.
12. Wrap the island with 0.010" ceramic cloth and seal the middle of the conductor into the ramp.
13. Pre-bend the conductor to fit the ramp area. Clamp it to the island plate.
14. Set additional insulation in place and wind the first turn over it.
15. Wind 13 turns with 60+ lbs of tension.

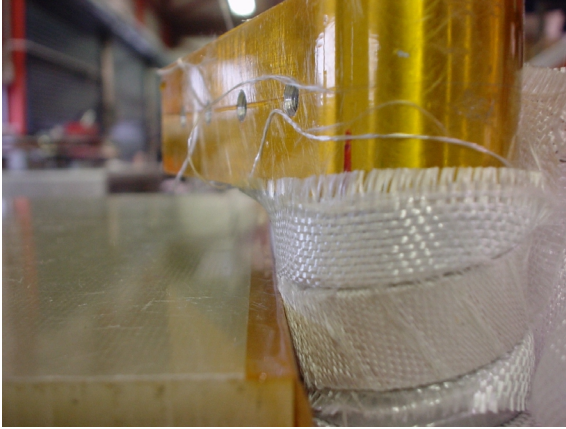


Figure 7. Cable sets into a layer jump groove.



Figure 8. Cable insulated with ceramic cloth in pole groove.



Figure 9. First turn wave propagation.

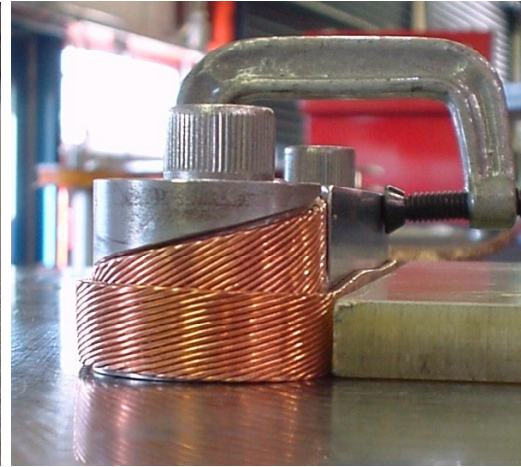


Figure 10. Bare cable wave created by 3D bending propagates for several first turns.

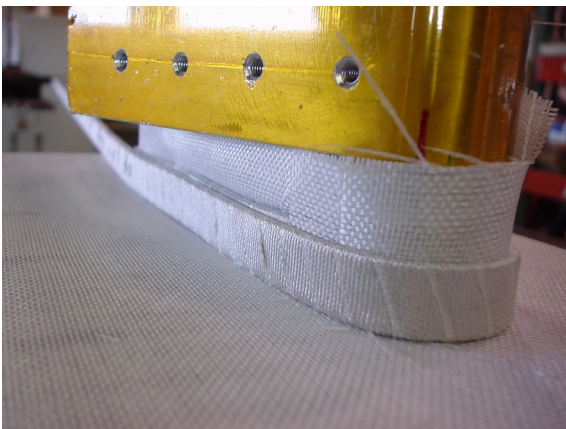


Figure 11. An additional insulation fills voids around second turn near a layer jump groove.

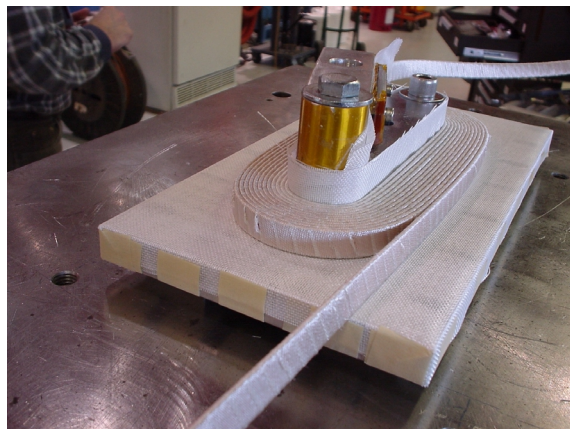


Figure 12. First layer completed.

16. Capture the 1st layer lead with the clamping fixture.
17. Cut the cable at the clamping fixture.
18. Measure and bag the extra conductor.
19. Place spool for the 2nd layer on the tensioner.
20. Remove the island clamp and the spool holding fixture.
21. Install interlayer spacers.

The interlayer spacer was placed on top of the first layer that was wound (bottom coil). It consists of two “C”-shape 10-layers ceramic insulators, each 40 mils ~1 mm thick. They were cut from rectangular stacks of cloth cured at 150°C for 30 min. These stacks were assembled together between two metal plates after the CTD binder was applied to each cloth layer. The spacers as installed are shown in Fig 12.

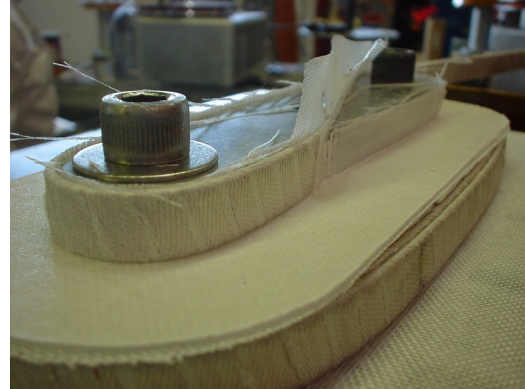
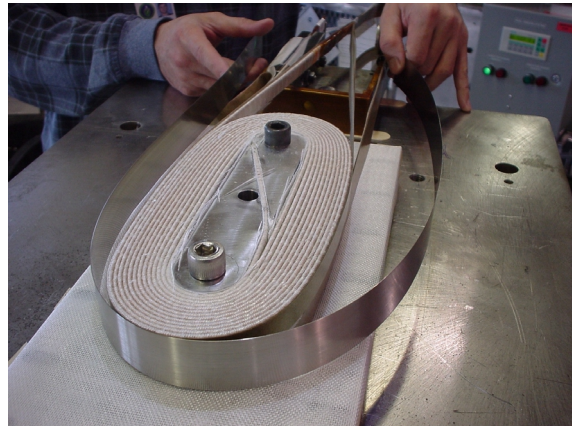
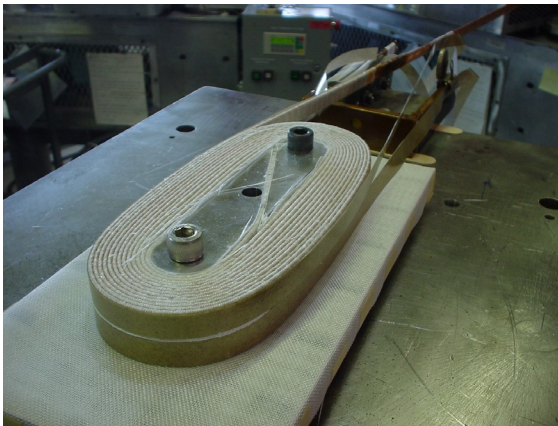


Figure 13. Interlayer spacers.

22. Verify that the second layer contact area on the island is covered with ceramic cloth, and start winding the second layer.
23. Continue to wind the second layer with 13 turns.
24. Clamp the lead of the 2nd layer in the clamping fixture.
25. Wrap the stack with stainless steel shims. The thickness was derived from the Coil Size Spreadsheet.



Figures 14, 15. Shim placement on the coil winding.

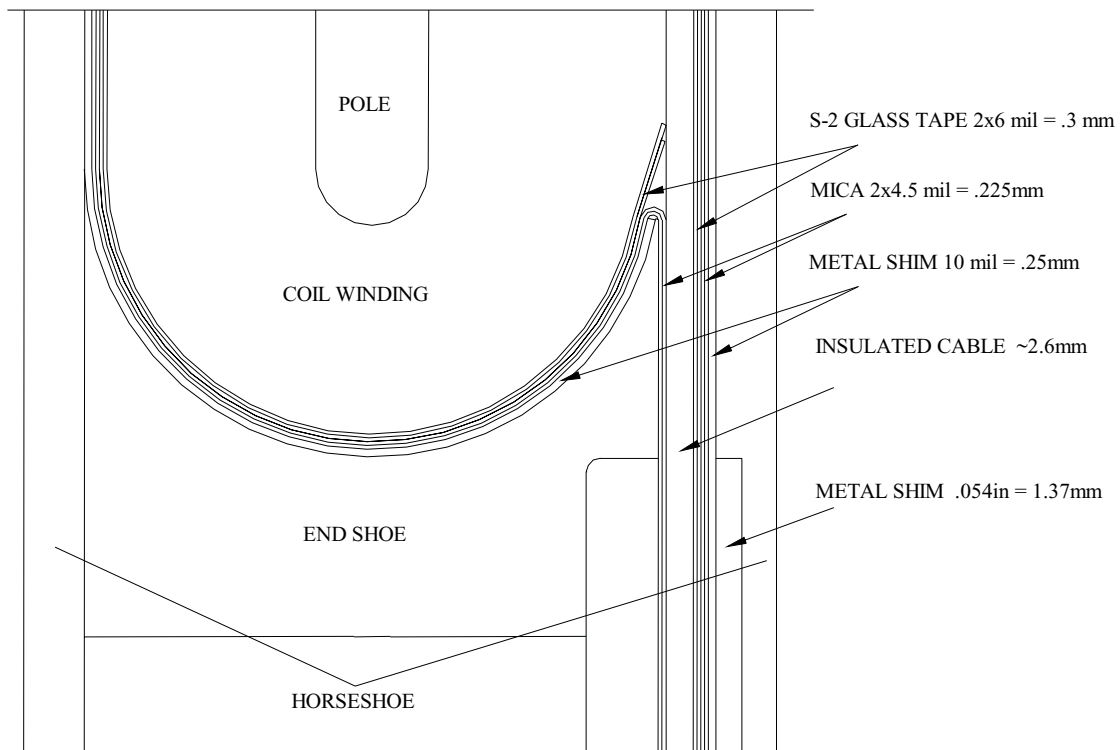
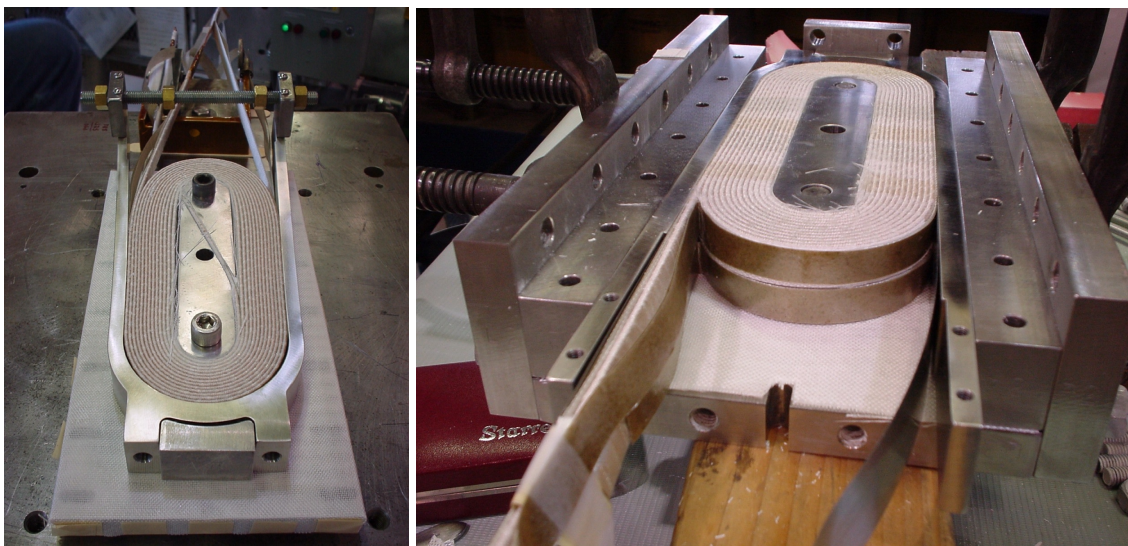


Figure 16. Coil shimming before reaction.

26. Use the spreading fixture to open the end of the horseshoe. Shove the horseshoe over the coil stack.
27. Use the spreading clamp to close the horseshoe.
28. Install the side pusher rails. Verify that the holes match the reaction plates.
29. Clamp the side rails to the plate with 4 small c-clamps. This will keep the rails from riding up during compression.



Figures 17,18. Horseshoe and side rails installation.

30. Install two studs into the plate and install the bottom pusher and plate.
31. Tighten up with washers and nuts to fully seat the horseshoe.
32. Install four studs in each side of the bottom plate.
33. Slide on the side rails and snug up with washers and nuts.
34. Clamp the side rails from underneath with large clamps.
35. Tighten up the side rails and chase with the nuts to reasonably snug up the package.
36. Remove the clamping fixture from the horseshoe.
37. Record the coil mechanical measurements for layer 2.

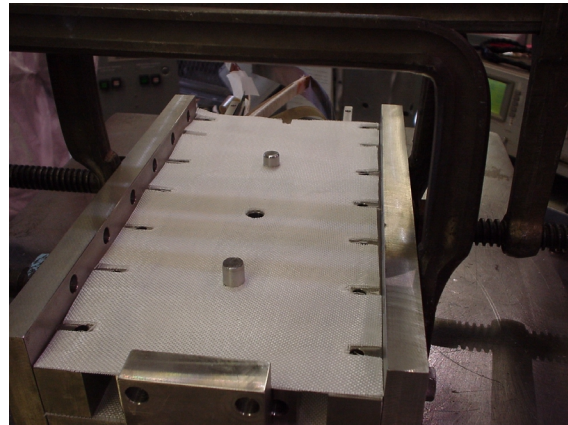
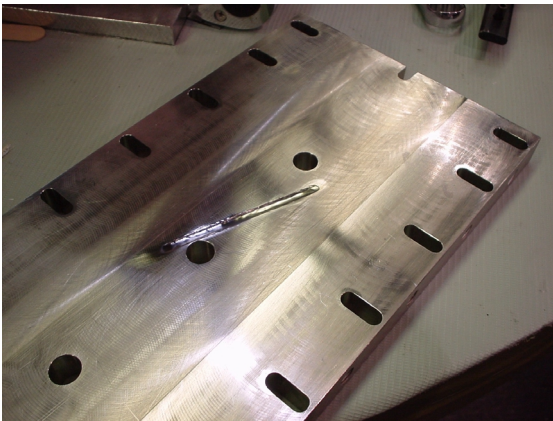
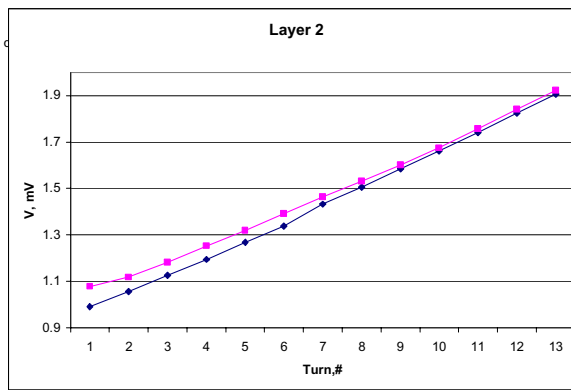


Figure 19. Modified side plate of reaction fixture with a safety groove for a waived cable.

Figure 20. Ceramic ground insulation.

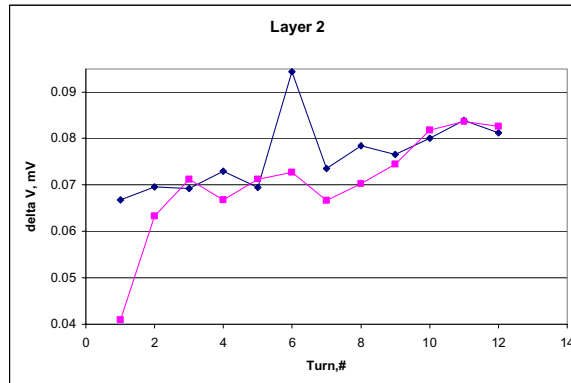
38. Perform the turn-to-turn electrical check on layer 2.
39. Cut the cable of the 2nd layer at the clamping fixture and measure and bag the leftover cable.
40. Remove the large side rail compression clamps.
41. Remove 4 small c-clamps.
42. Replace the three ½" bolts with the rounded pins pushed up from the bottom.
43. Replace a layer of .010" ceramic sheet over the layer 2 coil. Punch out the three ½" holes.
44. Install the top plate.
45. Install all the studs, washers and nuts in the top plate.
46. Unclamp the leads and remove the clamping fixture.
47. Remove the coil from the winding table and move it onto a bench.
48. Flip it over and remove the studs from the plate of the 1st layer.
49. Remove the plate of the 1st layer.
50. Record the coil mechanical measurements for layer 1.
51. Perform the turn-to-turn electrical check on layer 1.

Turn-to-turn layer 2				
#	R	delta	R	delta
1	0.9898	0	1.078	
2	1.0566	0.0668	1.1189	
3	1.1262	0.0696	1.1822	
4	1.1955	0.0693	1.2534	
5	1.2685	0.073	1.3202	
6	1.338	0.0695	1.3915	
7	1.4324	0.0944	1.4642	
8	1.5059	0.0735	1.5309	
9	1.5844	0.0785	1.6012	
10	1.661	0.0766	1.6757	
11	1.7411	0.0801	1.7575	
12	1.825	0.0839	1.8412	
13	1.9062	0.0812	1.9238	

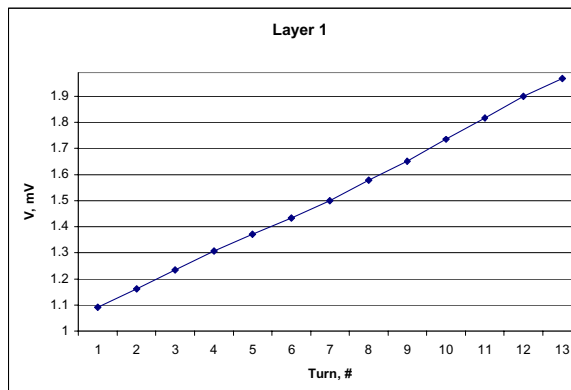


L	R	Q	F
22.0315	2.0612	2.42	1kHz
22.2187		0.08	20Hz

L	R	Q	F
21.221	1.9336	2.33	1kHz
21.583	2.0005	0.08	20Hz



Turn-to-turn layer 1			
#	R	delta	
1	1.091	0	
2	1.1622	0.0712	
3	1.235	0.0728	
4	1.3074	0.0724	
5	1.3725	0.0651	
6	1.4337	0.0612	
7	1.5004	0.0667	
8	1.5793	0.0789	
9	1.6523	0.073	
10	1.7344	0.0821	
11	1.8155	0.0811	
12	1.8985	0.083	
13	1.9678	0.0693	



L	R	Q	F
21.567	1.945	2.48	1kHz
21.282	2.043	0.08	20Hz

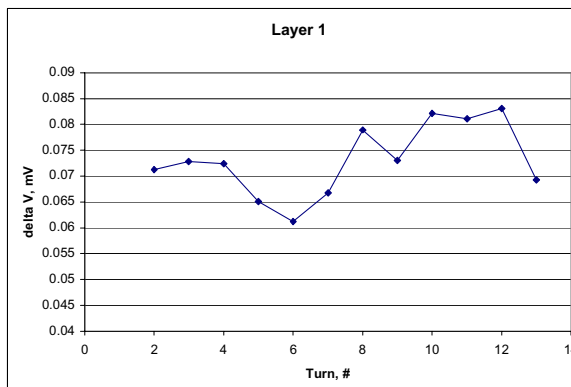
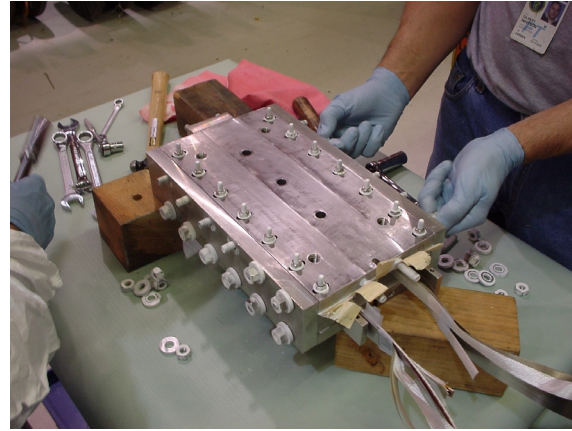
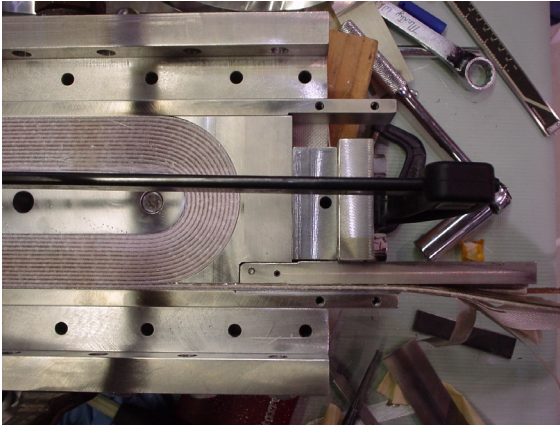


Figure 21. Coil turn-to-turn electrical test after coil winding.



Figures 22,23. End shoe placement and studs installment.

52. Rework end shoe to fit the radius of the conductor stack. Fill gaps with glass.
53. Assemble the lead end shoe with the two stainless lead support splints.
54. Figure the clearance for the splice support spacers and the total end shoe width.
55. Coat all the screws and holes with boron nitride spray.
56. Wrap the lead end of the coil stack with mica and push the shoe in and seat it.
57. Install the lead splice shims.
58. Install the lead and return pusher blocks.
59. Install the layer of .010" ceramic back over the 1st layer coil.
60. Install the layer one reaction plate over the coil.
61. Push the three 1/2" vented thru bolts through the plates. Align for venting and tighten the nuts.
62. Install the rest of the 3/8" studs, washers and nuts. Just snug up the nuts verifying that the side plates are pushing evenly on the rails.
63. Close the side rails.
64. Tighten the side rail nuts.
65. Install all the 1/4" thru bolts, washers and nuts.
66. Install the studs, plates, washers and nuts for the ends.
67. Snug up the plate nuts.
68. Tighten up all the 1/4" thru bolts.
69. Take and record package measurements on pre-reaction fixture sheet.
70. Verify that the coil is electrically open to the tooling.
71. Install the argon purging fittings and tubing.
72. Weld the ends of the conductor to seal them.
73. The package in now ready for heat treatment.

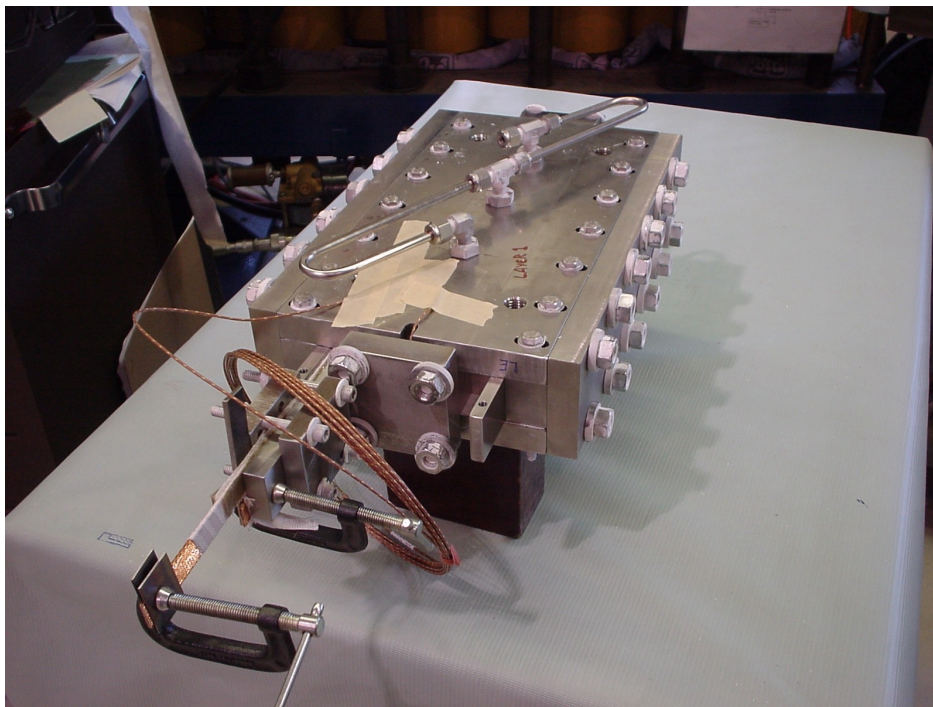


Figure 24. Packed coil in the reaction fixture.

SUB-SCALE PACKAGE REACTION FIXTURE

MAG # **SR-01** DATE: **12/9/2003** INITIALS: **MW**

LE ☐

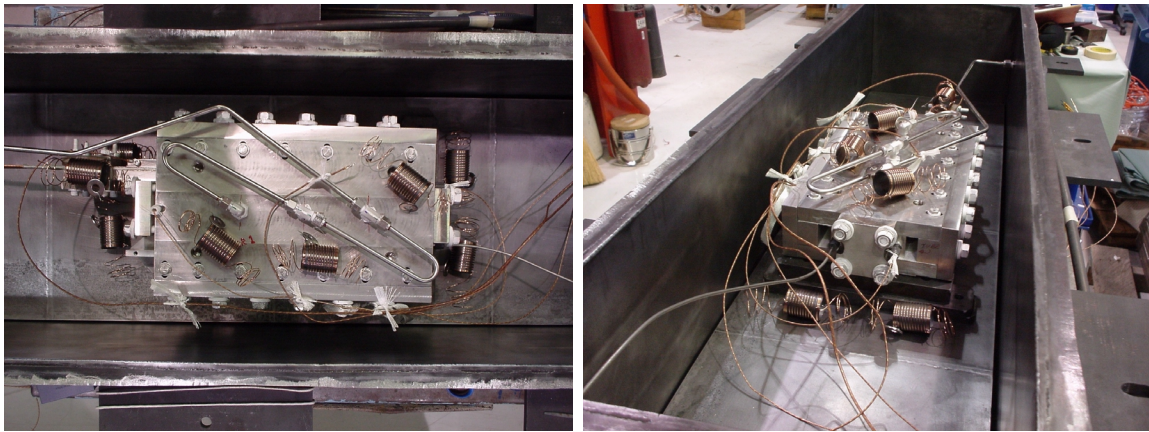
WIDTH, in		THICKNESS, in	
1	8.220	1	2.775
2	8.219	2	2.778
3	8.220	3	2.783
4	8.219	4	2.784

Notes: _____ After reaction

Figure 25. Mechanical measurements on the reaction fixture.

Coil Reaction

The coil heat treatment was performed in argon atmosphere at 660°C. The reaction fixture and a set of witness samples were placed inside a reaction retort as shown in Figs. 26 to 29. Two types of thermocouples read the magnet and retort temperatures: unshielded and “stainless-tube” shielded. The shielded thermocouple was introduced as unshielded thermocouples showed temperature readings that drifted down with time at $T_{\text{oven}}=650^{\circ}\text{C}$. After proper connections and welding of the top plate, the retort was placed inside of the oven. The PIT coil heat treatment cycle was: 25 °C/h up to 660°C and 170 h at 660°C (see Fig. 30 and Table 4). Retort inside views are shown before reaction in Figs 26, 27, and after reaction in Fig. 29.



Figures 26, 27. Inside views of the reaction retort before welding the top plate.



Figure 28. Reaction retort placed in the oven.
Figure 29. Reaction retort after heat treatment.

SR-01 coil, PIT conductor, heat treatment cycle : 25°C/h up to 660°C, 170 h at 660°C

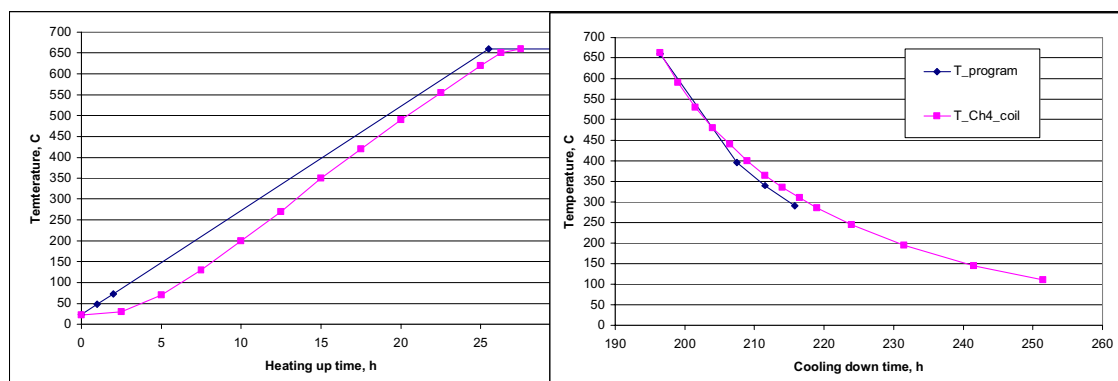


Figure 30. PIT reaction cycle.

Table 4. Reaction log for the PIT coil SR01 in IB3 oven.

DATE	TIME	PRESSURE	GAS FLOW	CH1	CH2	CH3	CH4	CH5	CH6	OVEN	CONTROL
		Psi	LPM								PANNEL
11-17-2003	3:25 PM	0.5	0.4	21.9	21.9	21.9	21.8	22.2	22.2	22	23
11-18-2003	7:00 AM	0.6	0.4	379.6	370.3	367.8	368.3	392	395.8	402	406
11-18-2003	11:30 AM	0.6	0.4	500.3	493.5	492	490.2	505.7	505.7	510	513
11-18-2003	3:20 PM	0.8	0.4	599.7	596.4	596.3	590	599.5	598.4	603	605
11-19-2003	7:00 AM	1.5	0.4	651.4	647.1	647	662.3	651.3	657.5	659	660
11-19-2003	11:00 AM	1.5	0.4	650.1	647.6	643.7	662.7	651.7	657.7	660	660
11-19-2003	3:15 PM	1.55	0.4	651.2	646.1	645.8	660.2	651	657.7	660	660
11-20-2003	7:30 AM	1.5	0.4	649.9	643	642.9	662.5	649.7	657.6	659	660
11-20-2003	11:25 AM	1.5	0.4	650.5	643.8	643.1	662.2	650.2	657.9	660	660
11-20-2003	12:45 PM	1.1	0.4	650.9	645.2	643.1	663.1	650.9	658.3	660	660
11-20-2003	3:40 PM	1.2	0.4	650.1	643.3	641	662.9	649.9	658.2	660	660
11-21-2003	7:00 AM	1.1	0.4	649.1	641	638.8	662	649.3	658	660	660
11-21-2003	11:30 AM	1.1	0.4	649.4	641.6	639.5	662.8	649.3	658	660	660
11-21-2003	2:45 PM	1.1	0.4	649.1	641.2	639	662.8	648.9	658.2	660	660
11-24-2003	7:20 AM	1.1	0.4	647.8	636.1	633.4	663.2	648	658.4	659	660
11-24-2003	11:25 AM	1.1	0.4	647.8	636	633.4	663.1	647.7	658.2	660	660
11-24-2003	3:15 PM	1.1	0.4	647.5	635	632.2	663	647.1	658.4	660	660
11-25-2003	7:15 AM	1.1	0.4	647.1	634.8	631.9	663.1	647.1	658.4	660	660
11-25-2003	12:35 AM	1.1	0.4	647.1	631.6	631.5	662.8	646.6	658.2	660	660
11-25-2003	3:15 PM	1.1	0.4	646.2	631.4	629	663.1	645.4	658.3	660	660
11-26-2003	7:10 AM	1	0.4	381.7	364	361.2	416.1	381.5	398.1	396	396
11-26-2003	11:00 AM	1	0.4	327	313.9	312.1	362	327	343.9	342	343
11-26-2003	3:20 PM	1	0.4	279.3	268	266.2	312.7	279.3	294.5	293	293
12-01-2003	7:10 AM	1	0.4	24.8	24.7	24.7	26.6	25	25.6	25	25
shift				3.9	16.2	14.7	-0.4	6.3	-0.6		

CH1 LE HORSE SHOE (Twisted and Crimped)

CH2 LE COIL (Welded K)

CH3 RE COIL (Welded K)

CH4 RE COIL (Stainless Steel Tube)

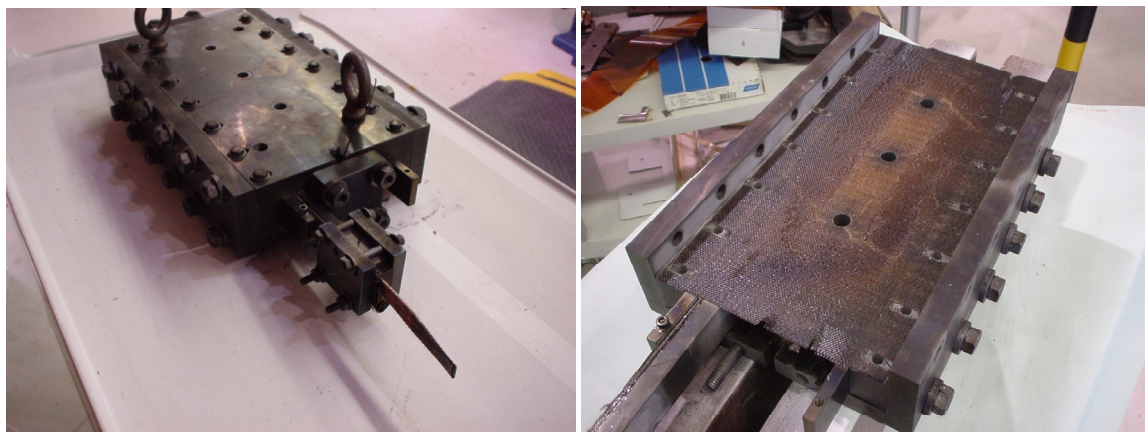
CH5 RETORT AIR (Twisted and Crimped K)

CH6 OVEN AIR (Stainless Steel Tube)

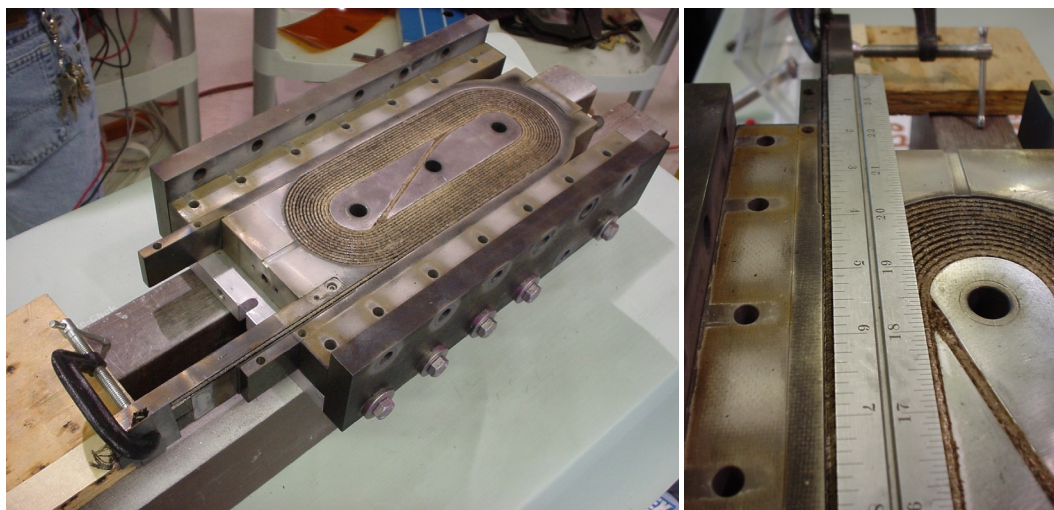
The data reported in Tab. 4 show the smallest number of “shift-down” value for thermocouples with “stainless-tube” shielding. Therefore, this type of thermocouples will be used for future reaction cycles.

Post Reaction Procedure

1. After reaction the flange welded to the retort can be opened using an air nibbler or grinder.
2. Remove door from retort and remove samples and strips that may be on top of coil.
3. Remove thermocouples and gas line from the coils and remove coils from retort.
4. Remove the coil from the oven and remove the $\frac{1}{2}$ " thru bolts and tubing.
5. Install the 2 $\frac{1}{2}$ " thru bolts to hold the plates and snug up.
6. Place the coil on the table (Top layer facing up). Record post reaction dimensions.
7. Remove the lead & return end pusher blocks. Take care not to disturb the reacted leads.
8. Loosen the $\frac{1}{4}$ " thru bolts and remove.
9. Remove all the $\frac{3}{8}$ " reaction nuts and throw them away. Save the washers, the studs.
10. Remove the top plate. Bag and label the glass.
11. Remove the side reaction clamping rails.
12. Hold the coil together with Jorgensen clamp.
13. Remove the end pusher blocks.
14. Visually inspect coil and insulation, take pictures and record post reaction coil voltage check.



Figures 31,32. Reaction fixture and ceramic insulation after heat treatment.



Figures 33,34. Visual inspection of the coil after reaction.

15. Cover the layer with Mylar and place a potting plate onto the coil and bolt in place.
16. Flip the coil over and remove the reaction plate. Bag and label the ceramic.
17. Visually inspect coil and insulation take picture and record post reaction coil voltage checks and measurements.
18. Record post reaction measurements on the form.

SUB-SCALE COILS BEFORE AND AFTER REACTION

MAG # **SR-01** DATE: INITIALS: **MW**

LAYER 1 LE

WIDTH, in

11/11/03

8.211

8.210

8.210

8.210

COIL WIDTH, mm

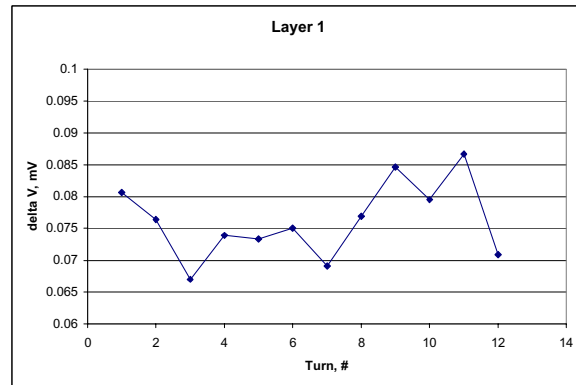
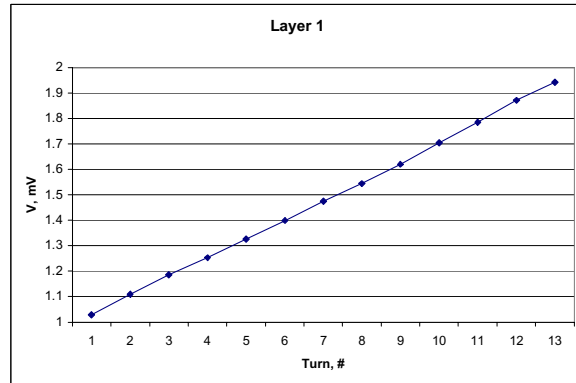
	Before	After
A1	30.46	31.55
A2	31.72	31.85
B1	33.12	33.32
B2	31.81	31.94
C1	31.70	31.96
C2	31.34	31.74
D1	31.57	31.91
D2	31.65	31.81

11/11/03 12/09/03

Notes: Measurements taken before 11/11/03 and after 12/09/03 reaction

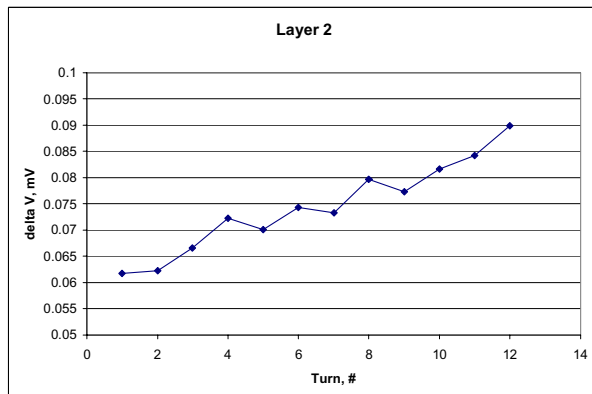
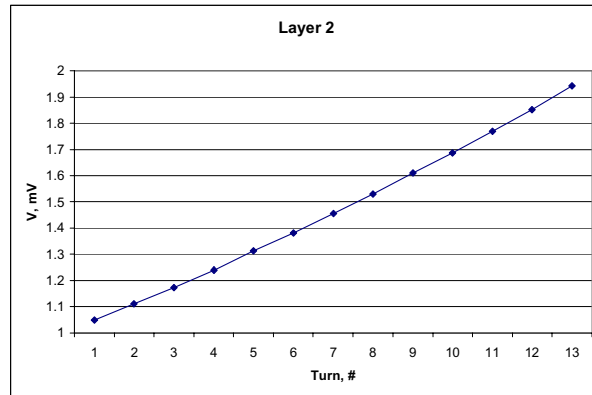
Figure 35. Dimension of the coil winding before and after reaction.

Turn-to-turn layer 1			
#	R	delta	
1	1.0284	0	
2	1.109	0.0806	
3	1.1854	0.0764	
4	1.2524	0.067	
5	1.3263	0.0739	
6	1.3996	0.0733	
7	1.4746	0.075	
8	1.5437	0.0691	
9	1.6206	0.0769	
10	1.7052	0.0846	
11	1.7847	0.0795	
12	1.8714	0.0867	
13	1.9423	0.0709	



Electrical test after reaction before splicing of #2 FNAL coil PIT cable 12-09-03

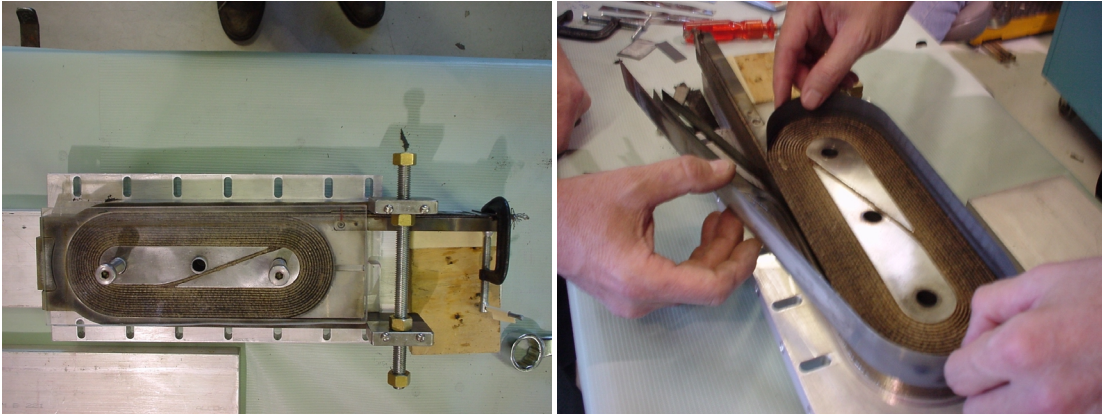
Turn-to-turn layer 2			
#	V[mV]	delta	
1	1.049	0	
2	1.1107	0.0617	
3	1.1729	0.0622	
4	1.2395	0.0666	
5	1.3117	0.0722	
6	1.3818	0.0701	
7	1.4561	0.0743	
8	1.5294	0.0733	
9	1.6091	0.0797	
10	1.6864	0.0773	
11	1.768	0.0816	
12	1.8522	0.0842	
13	1.9421	0.0899	



L	R	Q	F
		1.9664	
15.201	1.9605		1.4 1kHz
18.857	1.9223		0.07 20Hz

Figure 36. Coil turn-to-turn electrical test after reaction, before splicing.

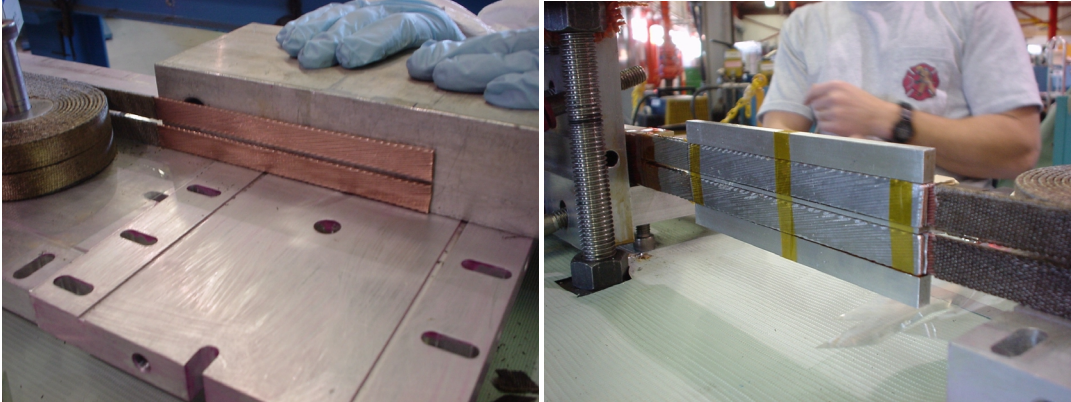
19. Remove all splice support shims.
20. Install lexan top plate to support the coil when side rails are off. Snug the $\frac{1}{2}$ " thru bolts.
21. Mark the glass sleeving for trimming to give clearance for the joint. Use the end shoe relief for reference.
22. Install the horseshoe-spreading fixture and spread the ends apart.
23. Remove the horseshoe.
24. Trim the conductor.
25. Mark the conductor for the splice joint length.
26. Remove the stainless reaction shims.



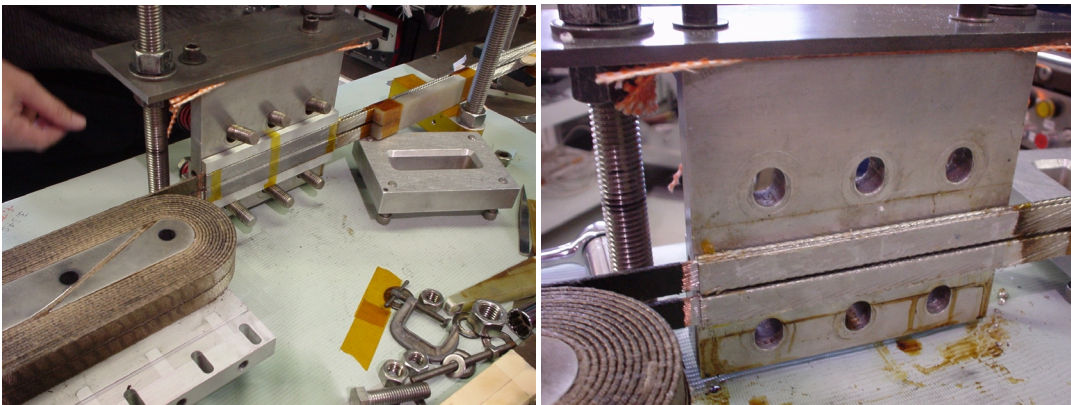
Figures 37,38. Removing the horseshoe and the metal shim.

27. Trim the sleeving away from the leads where they will be spliced. Remove any residue from the exposed area of cable with a wire brush.
28. Remove the end shoe and mica covering.
29. Remove thru bolts and slide the coil towards the end of the reaction plate. This will give room for splicing.
30. Secure the leads to the lab stands.
31. Prepare the four NbTi leaders. Tin the cut area and cut to the right length. Remove any high spots or burrs. Straighten the leads in preparation for installation.
32. Move the sleeve back toward the coil. Clamp a small paper towel piece around the cable to act as a block for the flux.
33. Install the solder fixture and stack up the leads and solder. Give $\frac{1}{4}$ " clearance on the coil side. Install the voltage tap wires. The lower lead will have the wires on the outside of the joints. The upper lead will have the wires on the inside of the joint. This will aid installation of the splice support rails and horseshoe.
34. Perform Leads Splicing.

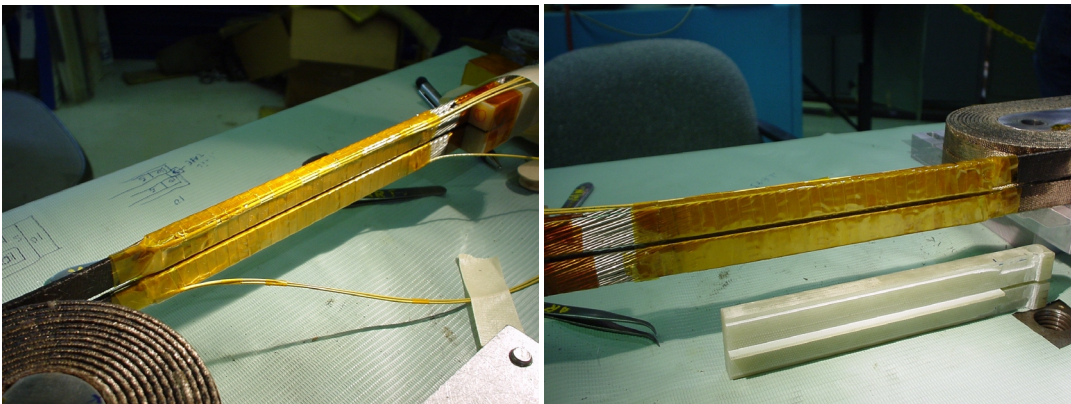
Both leads were spliced simultaneously. All six cables were properly shimmed and placed in a pre-adjusted fixture whose six bolts were hand tightened. The fixture was heated up to the tin melting point (220°C) and all bolts were further tightened till fixture gaps were completely closed. Six Voltage Taps were attached to the cables and the splices insulated by Kapton tape 4 x .002”.



Figures 39, 40. Clean Nb₃Sn leads, and shimmed stack of cables before splicing.



Figures 41, 42. Splicing fixture and view of leads after splicing.



Figures 43,44. Leads insulated by Kapton , and a modified G10 support.

Splicing log

NbTi keystone cable		pretinned	
thickness	width	thickness	width
2.25	14.5	2.4-2.68	14.6-15.0
.088x.078		.089-.084	

Nb₃Sn rectangular cable after reaction measured at the lead

thickness	width
2.0-2.2	14.3
.0786x.0796	

by mic	#	1	2	3	avr
top coil	thickness	0.0789	0.0806	0.0815	0.080
	width	0.559	0.556	0.558	0.558
bottom coil	thickness	0.077	0.0766	0.0778	0.077
	width	0.559	0.559	0.558	0.559

Splice geometry

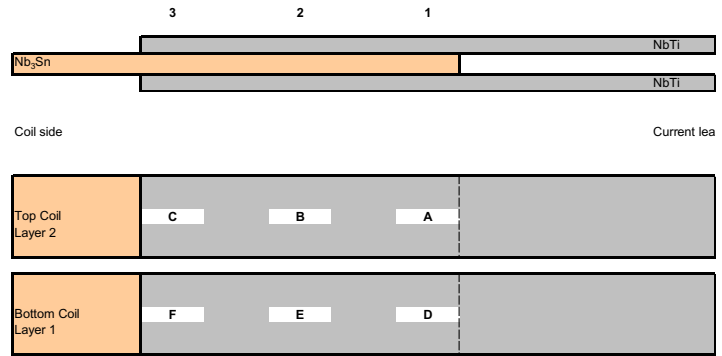


Figure 45. Measured cable dimensions.

Splicing fixture setup

Measurements: L=6in=152.5mm

Shim A

#	1	2	3	4	5	6
original	0.281	0.28	0.281	0.281	0.28	0.28
-0.02	0.257		0.258			0.257
0.003	0.26		0.261			0.26

Shim C

#	1	2	3	4	5	6
original	0.283	0.282	0.282	0.281	0.282	0.282
-0.02	0.258		0.2575			0.257
0.003	0.261		0.2605			0.26

Shim B

#	1	2	3	4	5	6
original	0.284	0.285	0.285	0.285	0.284	0.282
-0.02	0.2665		0.257			0.257
0.003	0.26		0.26			0.26

Calculated Splice Thickness

Shim	NbTi cable	Nb ₃ Sn cable	NbTi cable	Solder x 2	delta
0.261	0.088	0.08	0.078	0.015	0 top
0.261	0.088	0.077	0.078	0.018	0 bottom

Final Measurements of the completed Splices

by mic	#	1	2	3	avr	predicted	delta	solder x 2
top coil	thickness	0.2552	0.2551	0.2566	0.256	0.261	0.005	0.010
	width	0.578	0.575	0.578	0.577			
bottom coil	thickness	0.2551	0.2553	0.2559	0.255	0.261	0.006	0.012
	width	0.581	0.576	0.58	0.579			

Insulated Splice Thickness

Insulation: 4x1.3=5.2 mil Kapton w polyimid

by mic	#	1	2	3	avr
top coil	thickness	0.2693	0.2682	0.2673	0.268
bottom coil	thickness	0.2685	0.2676	0.267	0.268

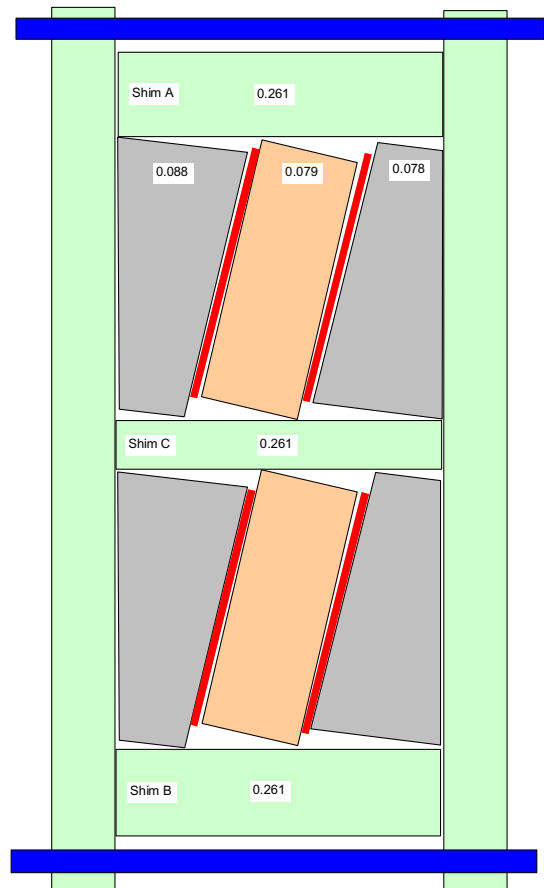


Figure 46. Splicing fixture parameters and final splice size.

35. Wrap the joint area with 4 x 0.002" Kapton tape. Continue about 1" past joint ends.
36. Tie off the voltage tap wires to the splice.
37. Push the coil back into position on the plate. Secure with three thru bolts and lexan cover.
38. Check for electrical continuity of the splice tap wires to the coil.
39. Tape the layer 1 (Bottom) inside splice tap wire to the splice. This will secure it so it will not get pinched later.
40. Clean all parts with abrasive.
41. Mold release the horseshoe.
42. Cut Nema shims to approximate the thickness of the reaction shims.
43. Punch holes through the shims for epoxy flow.
44. Install the heater and solder the four NbTi leaders onto the leads.
45. Wrap the shims around the inside on the horseshoe and install it over the coil.
46. Use the potting bottom plate and reaction pusher block to seat and tension the horseshoe.
47. Coat end shoe contact surface with .003" Kapton.
48. Grind a bevel on the layer 2 (Top) splint for splice tap wire clearance.
49. Install Nema supports to the end shoe.
50. Make two blocks of Nema to take up the difference in the coil against the splice support splints. Leave clearance at the bottom so the epoxy coming up the splice will return to the reservoir. Drill holes so the upper 10-32 holes of the splint can be accessed.
51. Glue these blocks onto the splints.
52. Install the end shoe assembly.

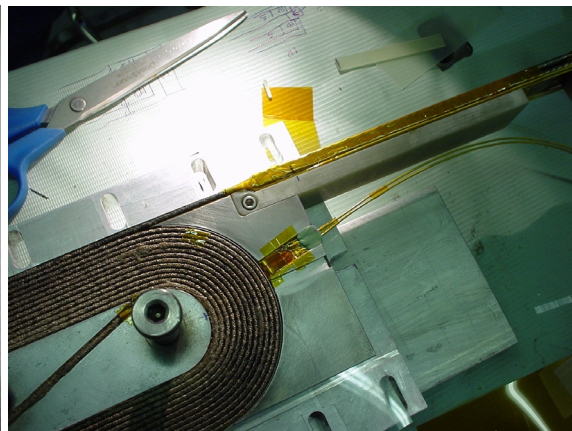
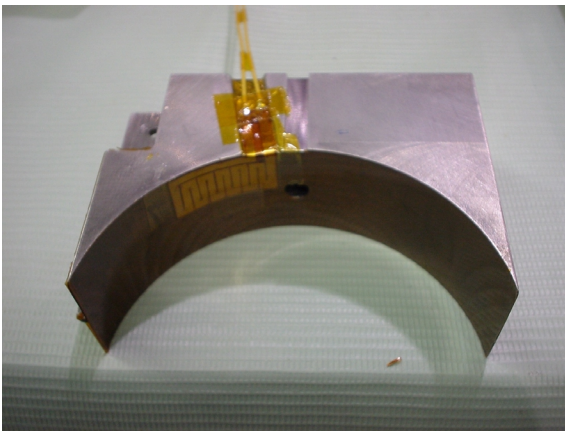


Figure 47. End shoe with insulated Spot Heater.

Figure 48. Installed end shoe with G10 support for the leads.

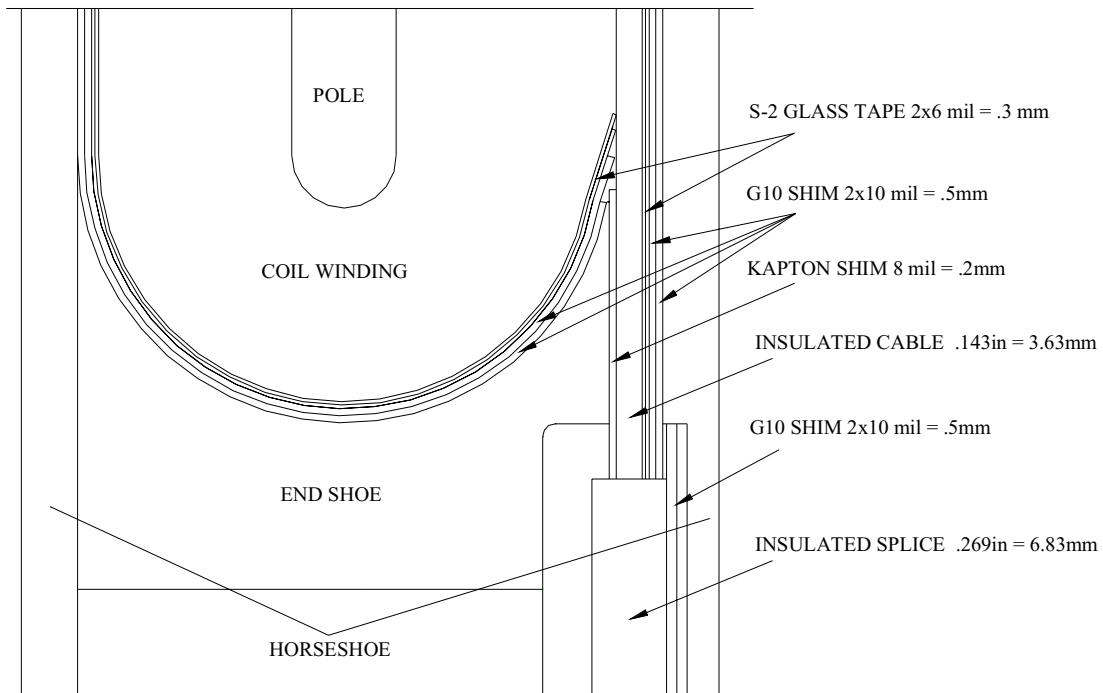


Figure 49. Coil shimming before impregnation.

53. Install the potting end shoe tensioner in place and snug the shoe into the coil.
54. Tighten the side rails with a Jorgensen clamp.
55. Make a Nema shim to insulate the joint and fill any gaps.
56. Secure the joints with small Nema tabs to the horseshoe and Nema splice supports.
Verify that the Nema tabs have been mold released so they do not stick to the joints.
57. Release the shoe tensioner and remove it.
58. Release the bottom tension plate and remove it.
59. Remove Jorgensen clamp slowly
60. Remove the thru bolts and vacuum the coil surface.
61. Pack glass in all recesses.
62. Seal the lower set of 10-32 holes in the horseshoe with RTV.
63. Install 2 x 0.005" glass cover onto the coil surface.
64. Drop the potting plate over the coil using 1/2" bolts.
65. Bolt the coil and gently flip over. Watch for the leads!
66. Remove bolts and the plates and Mylar cover.
67. Pack glass in all recesses.
68. Use of q-tip and mold releasing the reservoir are to aid in removal of cured epoxy.
69. Add Nema shim to the splice area and support with tape.
70. Install 2 x 0.005" glass cover onto the coil surface.
71. Install the potting pusher rails.
72. Install the potting plate.
73. Install thru-bolts with o-rings (-014 Buna) and tighten. Supplement sealing with RTV on o-ring area.

74. Install the epoxy inlet pipe and barb.
75. Install the base pusher block and bar. Snug up the four bolts.
76. Install the end shoe-pushing fixture. Use RTV to seal the two 3/8" bolts from epoxy.
77. Make a block for the pushing bolt to press against. Relieve it for epoxy flow.
78. Snug up the pusher hand tight.
79. Install the aluminum potting side rails and all 3/8" bolts.
80. Install all the 1/4" bolts and hardware and snug up to 60 inch lbs.
81. Torque the side rails until parallel.
82. Record the potting fixture measurements.
83. Perform and record electrical measurements.
84. Install the potting fixture standing angles.
85. Plumb the tubing and install into the potting chamber.

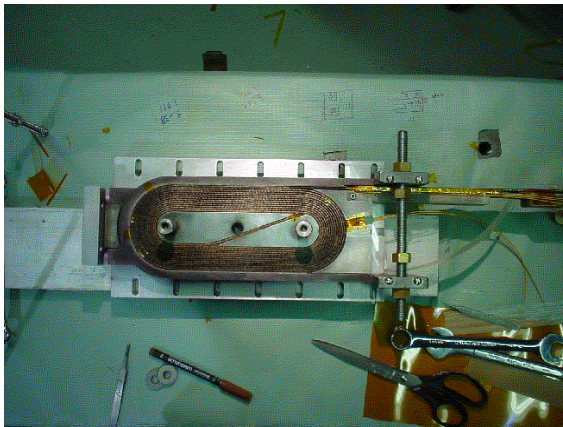


Figure 50. Horseshoe installation over the coil.

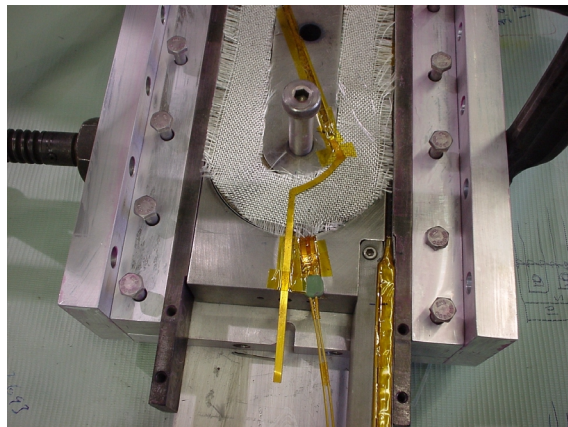


Figure 51. Middle point voltage tap made of a copper foil strip.

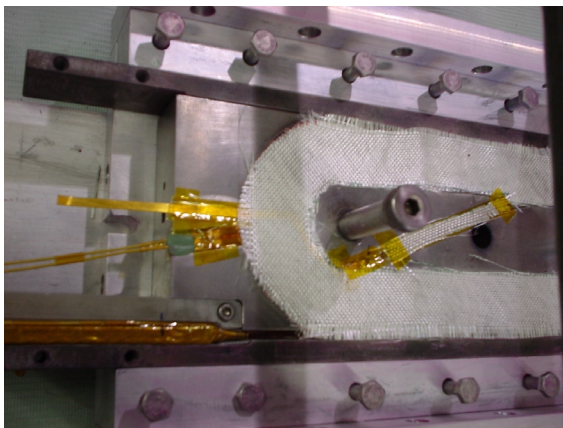


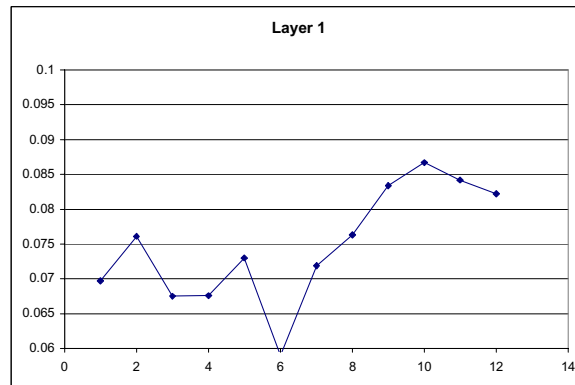
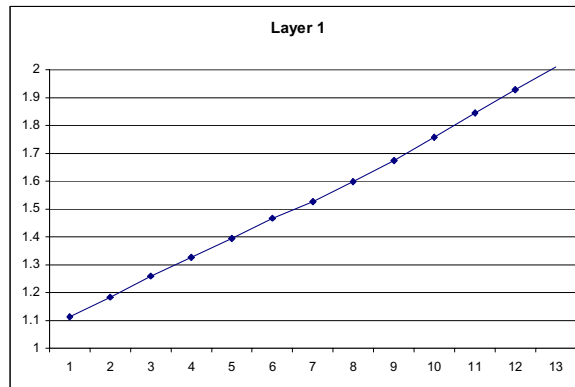
Figure 52. S-2 glass coil ground insulation.



Figure 53. Filled gaps around splice area.

Turn-to-turn layer 1		
#	R	delta
1	1.1132	0
2	1.1829	0.0697
3	1.259	0.0761
4	1.3265	0.0675
5	1.3941	0.0676
6	1.4671	0.073
7	1.5261	0.059
8	1.598	0.0719
9	1.6743	0.0763
10	1.7577	0.0834
11	1.8444	0.0867
12	1.9286	0.0842
13	2.0108	0.0822

Rb 2.101
Rf 2.033



Turn-to-turn layer 2		
#	V[mV]	delta
1	1.1034	0
2	1.1774	0.074
3	1.2482	0.0708
4	1.3181	0.0699
5	1.3903	0.0722
6	1.4634	0.0731
7	1.5379	0.0745
8	1.6203	0.0824
9	1.6918	0.0715
10	1.7698	0.078
11	1.8504	0.0806
12	1.9104	0.06
13	2.0096	0.0992

L 14.92
jumping 1.9769 jumping 20Hz

R 2.1071

Q 1.88 1kHz

F

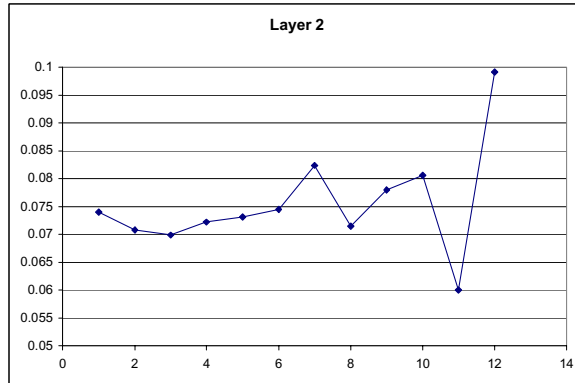
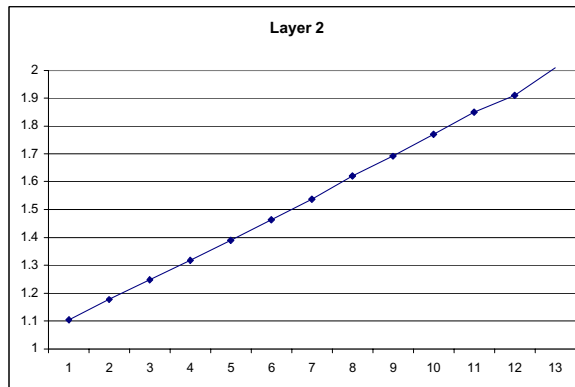
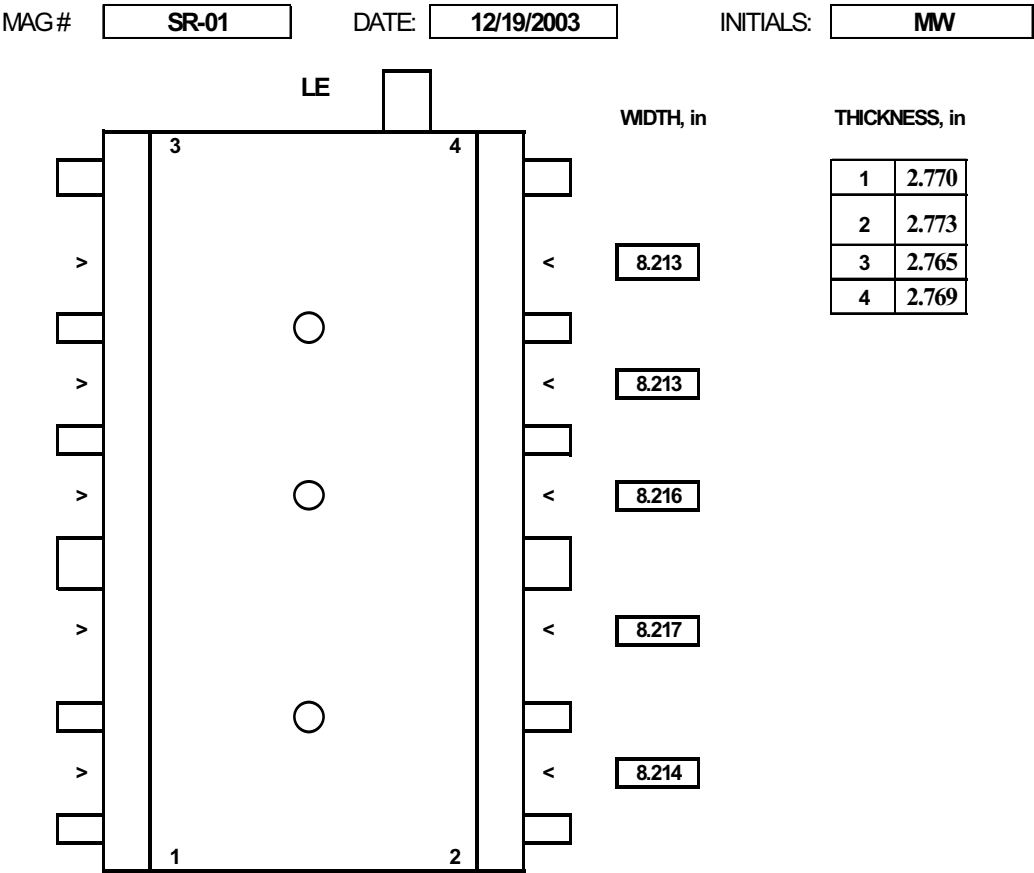


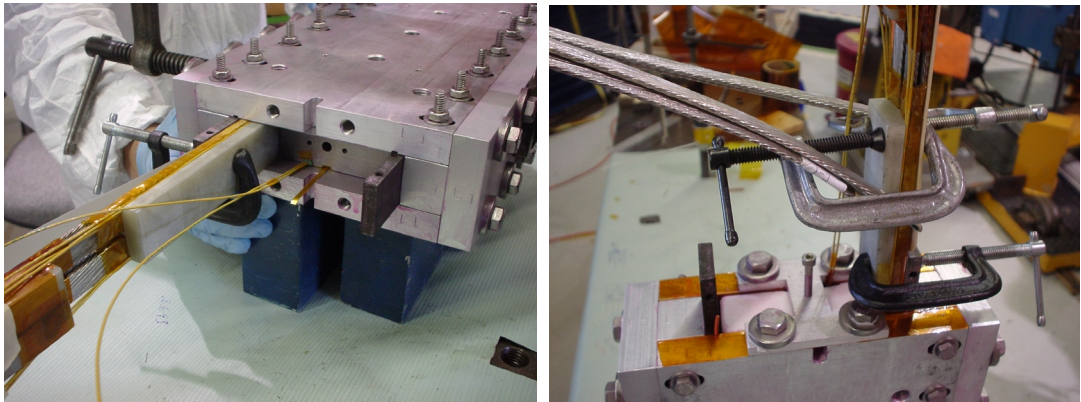
Figure 54. Coil turn-to-turn electrical test after splicing.

SUB-SCALE PACKAGE IMPREGNATION FIXTURE



Notes: 3.5mil Kapton with adhesive between coil and top/bottom plates before impregnation

Figure 55. Mechanical measurements of the impregnation fixture.



Figures 56,57. Impregnation fixture with cable support around splice area.

Coil epoxy impregnation

The fixture was pumped out in IB2 vacuum oven for 48 h.

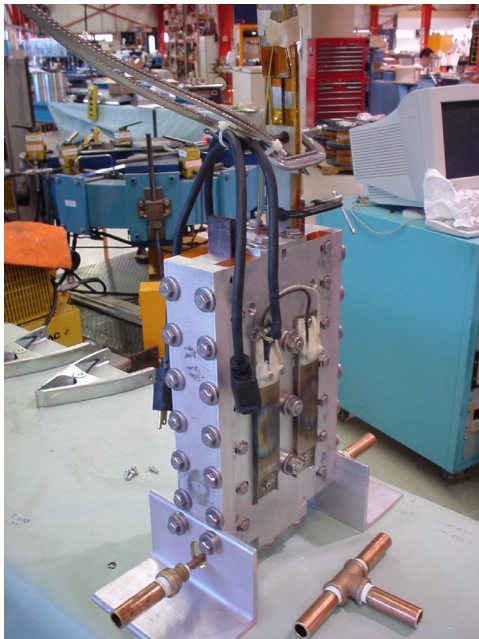
Material Designation Parts by weight:

Resin Part A 7.5 Kg

Hardener Part B 6.75 Kg

Accelerator Part C 112.2 g

Start epoxy mixing	6:53 a.m.	
Start heating	7:13 a.m.	T=30C-40C-45C-60C
Start out gassing	7:45 a.m.	
Stop	8:30 a.m.	
Vacuum = 45 microns		
Vacuum at tank = 10psi		
Start flow to bucket	11:05 a.m.	
Start flow to magnet	8:55 a.m.	
Flow rate	0.5 cm per sec	
Vacuum at the vessel 53 micron		
Epoxy at top of the fixture	9:50 p.m.	
Stop epoxy flow	10:00 p.m.	
Shut down vacuum	10:02 a.m.	
Maintained 55C heat to coil		
Start cure cycle	12:30 p.m.	125C for 21 hrs
Finish cure cycle	9:30 a.m.	(next day)



Figures 58, 59. Assembled impregnation fixture and fixture connections inside a vacuum oven in IB2.

Post Potting Procedure

1. Remove the top of the potting fixture.
2. Unhook all the heater plugs and thermocouples.
3. Remove the coil and set on a table.
4. Remove the upper push support plate and mirror.
5. Remove the angle stands from the potting fixture.
6. Lay the coil up on blocks and remove the lower pushing plate and block.
7. Remove the feed tube and elbow.
8. Remove all the 1/4" thru bolts and take out the side pusher rails.
9. Push out the shoulder bolts in the arbor press.
10. Remove the top plate and inspect the coil.
11. Remove the flashing that is on the horseshoe.
12. Remove the RTV in the lower 10-32 holes in the horseshoe. Tap out.
13. Remove the epoxy that is in the reservoir area.
14. Perform the mechanical measurements.
15. Take and record all electrical measurements.
16. Remove the 10-32 bolts and lead support Nema pieces from the horseshoe.
17. Install the horseshoe support plate to the horseshoe.
18. Prepare the Nema cover sheets and skins.

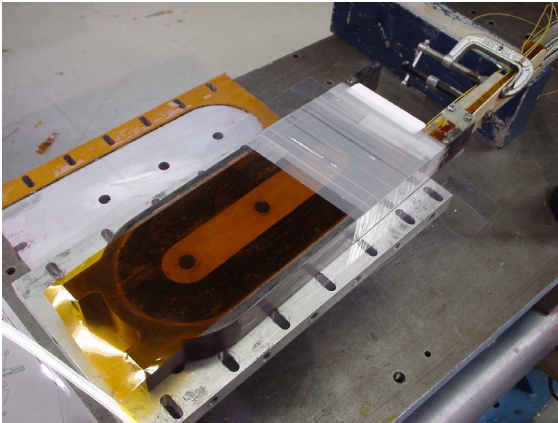


Figure 60. Impregnated coil block temporary wrapped by shrink tape to prevent a horseshoe separation.

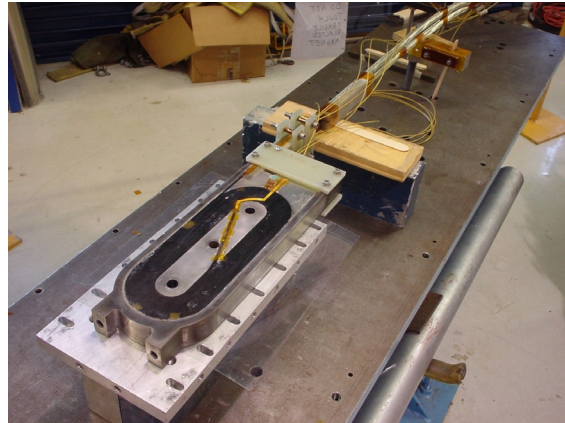


Figure 61. A G10 clamp was installed on the horseshoe legs.

Coil Block Shimming

To prevent brittle coil conductor from over compression, the thickness of the pole island, the coil, the end shoe and the horseshoe sizes should be the same. We control these dimensions by micrometer at six locations. Then the coil and the horseshoe were properly shimmed with Kapton.

SUB-SCALE COILS BEFORE AND AFTER SHIMMING

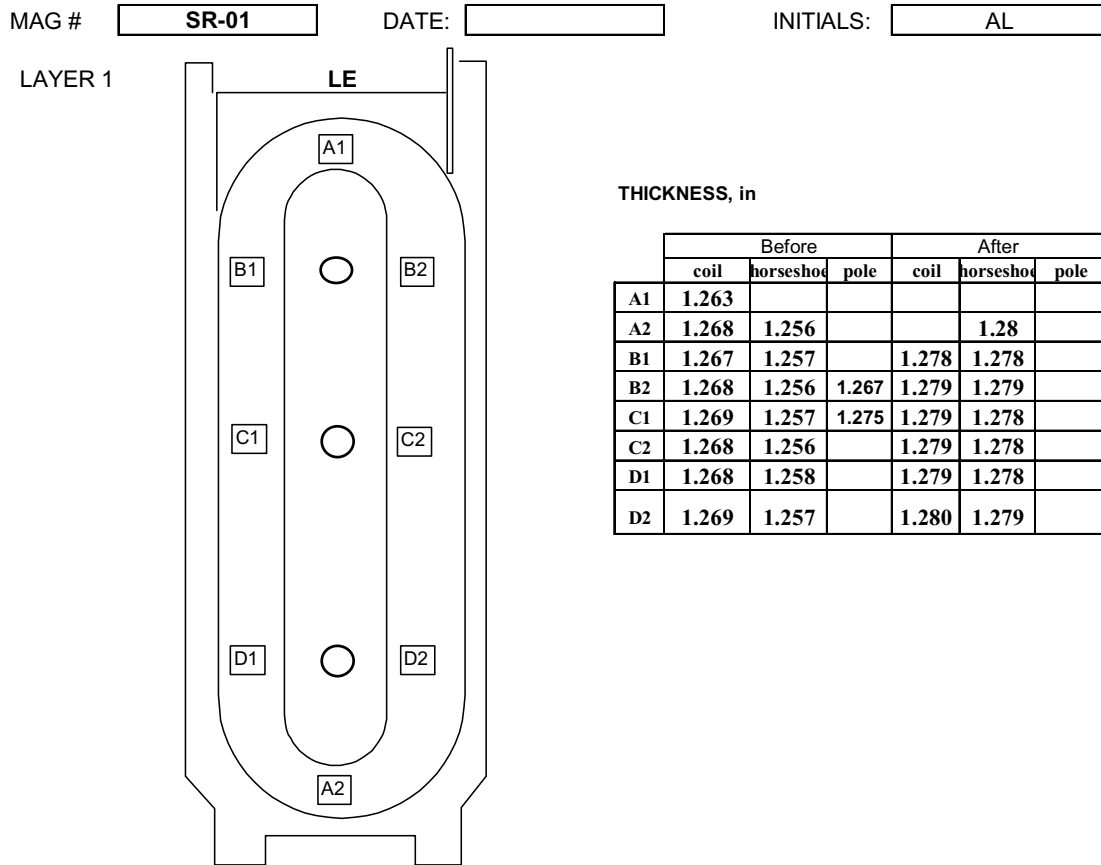


Figure 62. Size of the coil block before and after shimming.

To check a pressure distribution coming from 12-pressure pad bolts a Fuji film test was performed on the coil block.

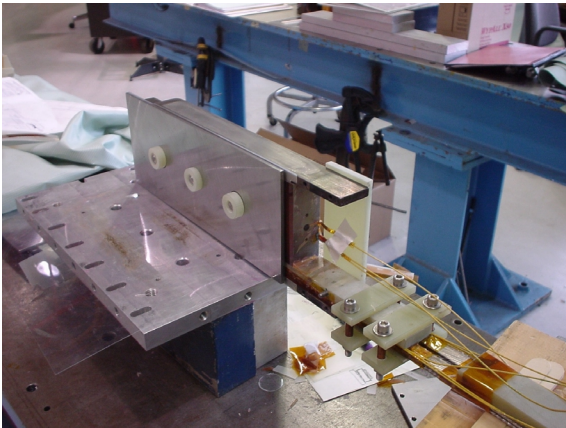


Figure 63. Skin installation.

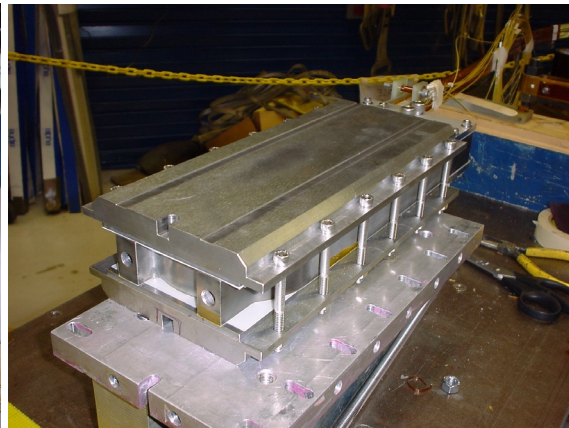


Figure 64. Coil block assembly during the Fuji test.

Results are shown in Fig. 65 (Fuji film max pressure of 10-12 MPa.). The pole island and the horseshoe are the parts most loaded. The coil has several spots with stress concentration. These spots correspond to cable wave propagation (as a result of the complicated 3D bending of a wide conductor at the layer jump groove) for several first turns during coil winding.

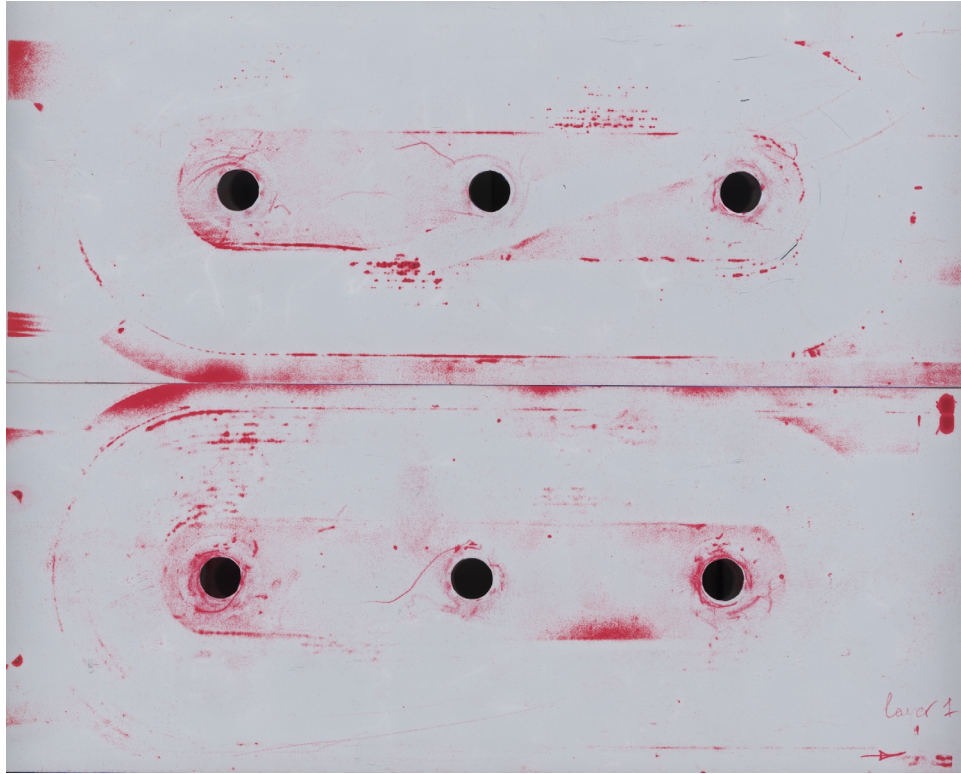


Figure 65. Results of Fuji film test.

Cylinder-Yoke Pre-assembly

Cylinder-yoke pre-assembly is a part of the final assembly procedure. It allows checking bladder and instrumentation. Technological shim sizing, shim installation and removal can be tested as well. After this step, the shimmed yoke will load the aluminum cylinder and the coil cavity will be large enough for coil block insertion.

An overview of the setup is shown in Fig. 66. A metal brick substituted the coil for this step. Only one bladder pressurized the structure from inside till 77 mil thick metal strips were inserted between the two yokes (Fig. 67).

The final measurements of the coil cavity are shown in Fig. 68. Bladder's "travel" was 80 mil for a shim thickness of ~0.14". Eight resistive strain gauges glued to the cylinder were used to monitor the stress level. All gauge data are summarized in Fig. 80.



Figure 66. Mechanical model used for the cylinder yoke pre-assembly.

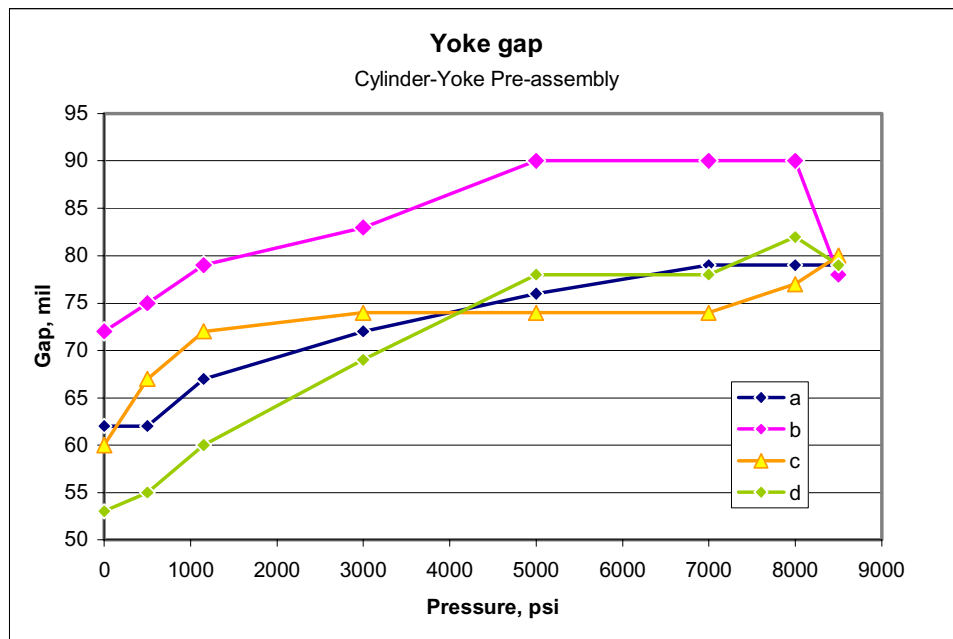
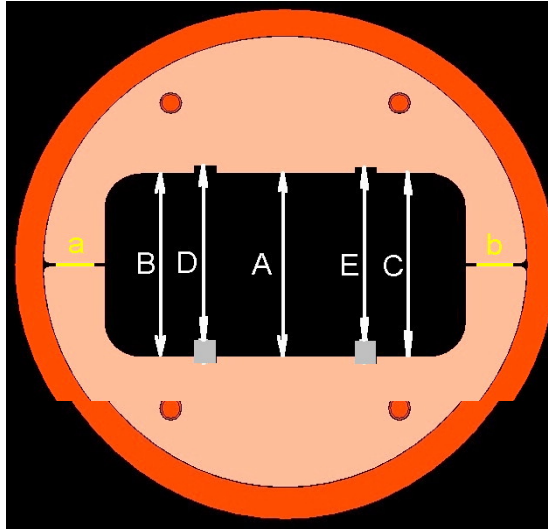


Figure 67. Results found for a mechanical model used for cylinder yoke pre-assembly

Cylinder-Yoke Pre-assembly



6	RE
5	
4	
3	
2	
1	LE

Total L=12in

All numbers in inch

#	1	2	3	4	5	6	min	max	delta
A	3.425	3.427	3.425	3.427	3.423	3.426	3.423	3.427	0.004
B	3.425	3.428	3.425	3.427	3.424	3.427	3.424	3.428	0.004
C	3.426	3.428	3.426	3.428	3.424	3.426	3.424	3.428	0.004
D	3.33	3.329	3.327	3.331	3.332	3.333	3.327	3.333	0.006
E	3.325	3.324	3.325	3.329	3.33	3.329	3.324	3.33	0.006
a	0.077	0.077	0.077	0.077	0.077	0.077			
b	0.077	0.077	0.077	0.077	0.077	0.077			

Gap A 3.423-3.081=0.342 :2 = 0.171

Gap D 3.327-3.004=0.323 -key -0.296 = 0.027 "+delta" one-side shim 0.033 **0.0165**

Gap E 3.324-3.004=0.320 -0.296 = 0.024 0.03 **0.015**

Figure 68. Cavity size measurements after cylinder-yoke pre-assembly.

Structural Assembly Procedure

1. Lift the bottom pressure pad plate and set it on a table.
2. Install thick 1" Nema spacer washers in the plate.
3. Install the 3 Nema coated metal pins through the coil into the bottom pad.
4. Install the bottom skin.
5. Lay out a .005" Nema sheet punched for a ½' thru holes onto the skin.
6. Install the coil layer 1 facing center of stack.
7. Lay out a .005" Nema sheet punched for a ½' thru holes onto the skin.
8. Install thin 1" Nema spacer washers onto the coil.
9. Install the top skin.

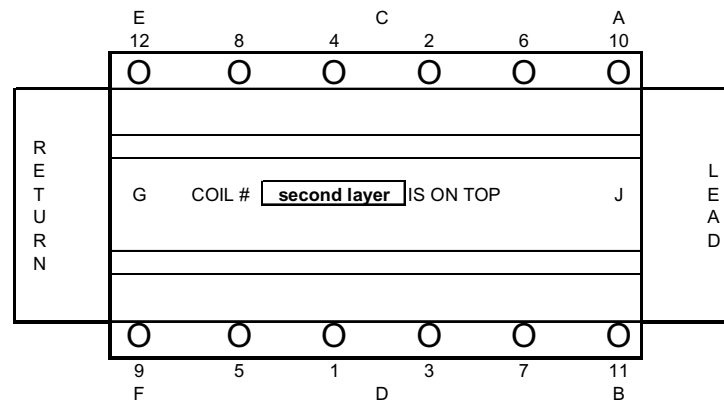


Figures 69, 70. G10 sheets of ground insulation.

10. Place the top pad onto the coil package. Verify that pins seat fully.
11. Sparingly apply anti-seize to all the tie bolts and install them through the pads.
12. Snug up all 12 bolts and take and record thickness measurements.
13. Begin the torque sequence and record measurements and data as needed.

SUB-SCALE PACKAGE ASSEMBLY SEQUENCE

MAG # **SR-01-PIT** DATE: **1/13/2004** INITIALS: **DS**



Torque in inch pounds

	Base	24 inch lbs	48 inch lbs	72 inch lbs	96 inch lbs
A	3.01	3.008	3.007	3.007	3.006
B	3.009	3.007	3.007	3.007	3.007
C	3.01	3.007	3.006	3.005	3.005
D	3.007	3.006	3.005	3.005	3.004
E	3.012	3.008	3.007	3.006	3.005
F	3.008	3.008	3.007	3.007	3.007
J					3.081
G					3.083

A-F is the measurement at the indicated positions of the coil package thickness.

Figure 71. Sequence of coil block assembly.

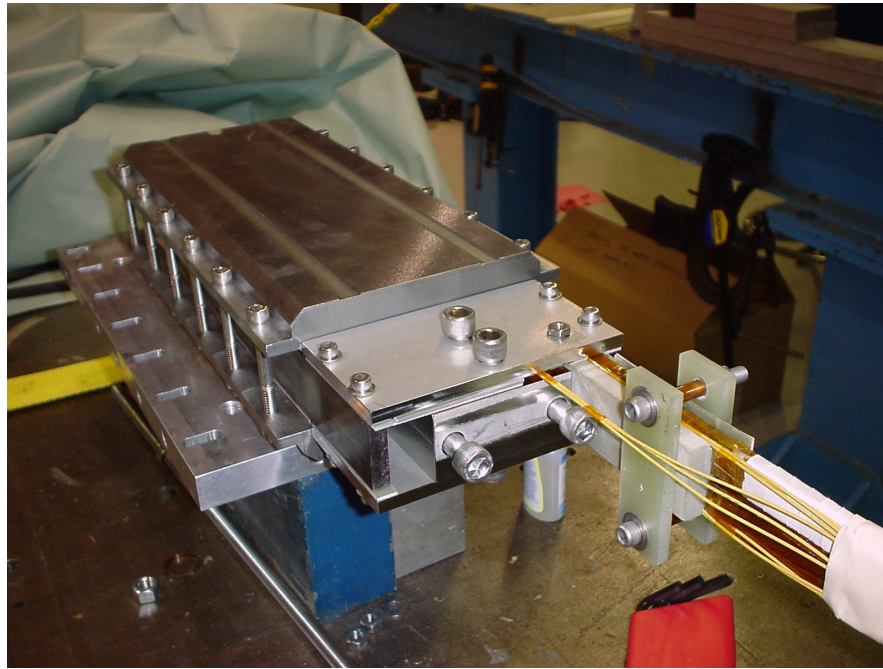


Figure 72. Assembled coil block.

14. Place the magnet into the yoke cavity.
15. Torque the 4 axial tension bolts to 12 inch lbs.
16. Use .300 keys on the bottom. (SC-03)
17. Install and align the upper bladder. Shim with assorted material until there is no gap.
18. Have ETs hook up all the gauges to monitor the expansion process.
19. Hook up the bladder pump and cycle to remove the trapped air. Record process and data onto the bladder expansion log sheets.
20. Bring the upper to the final pressure, and shim according to engineering determined size.

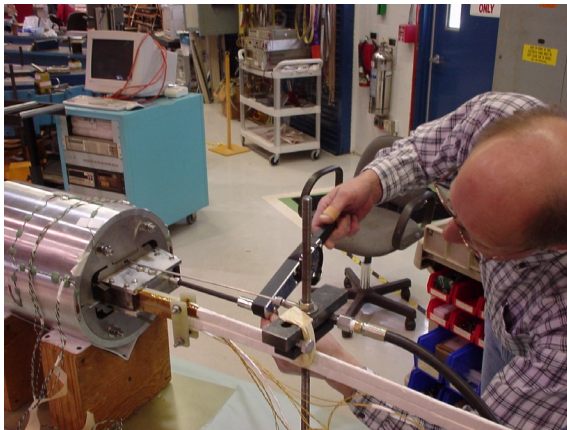


Figure 73. Torque the 4 axial tension bolts.

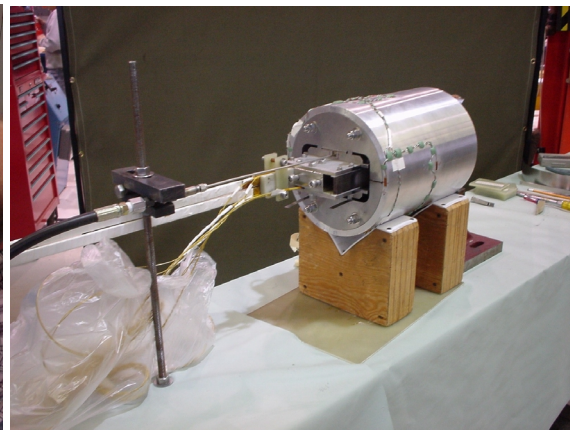


Figure 74. Final loading.

21. Once final shimming has been completed, remove the bladders and pump.
22. Have ETs affix all the wiring to the Hypetronics plugs.
23. Tie off and organize all the sensor wires.
24. Perform and record the electrical checks.
25. Perform Hi-pot procedure on the total magnet.
26. Lift the header out of the stand and set it over the magnet assembly. Run the washers and nuts up on the bottom.
27. Lift the whole assembly and place it back into the stand. Make sure to clamp it in place for safety.
28. Fasten the header leads to the coil. Use 3 Nema support pieces to secure the leads.
29. Have the ETs finish their hookups and checks.
30. Lift the magnet and place it into the cryostat.

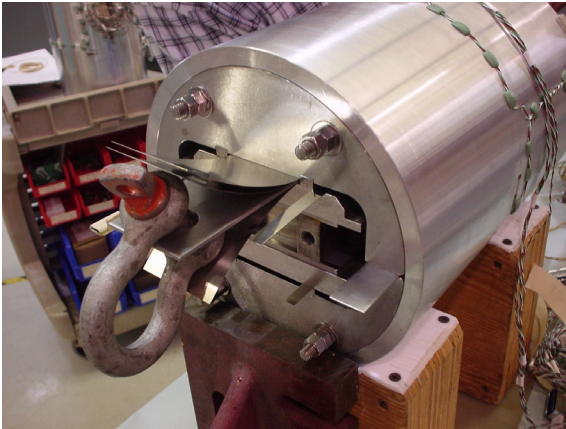


Figure 75. Bladder protection shims.

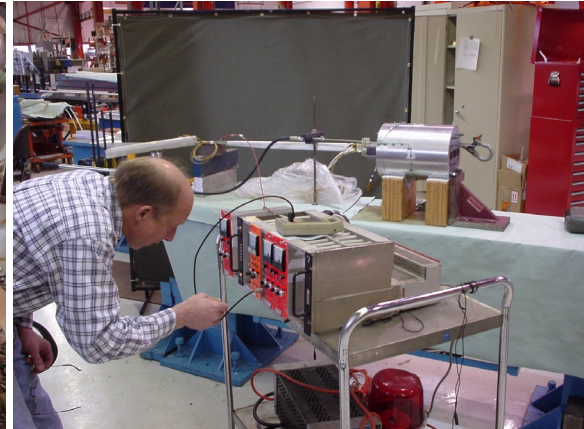


Figure 76. Hi-pot test.



Figure 77. Removing of the technological shims.

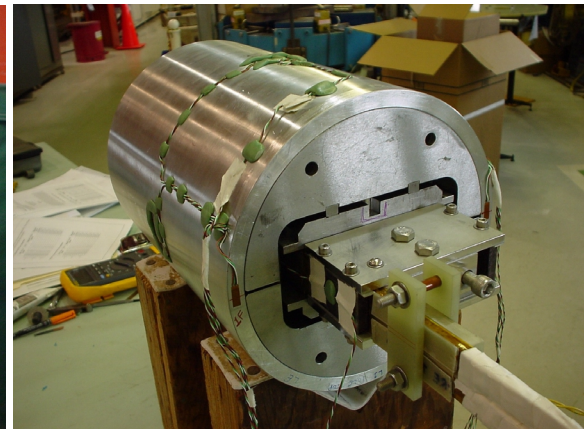


Figure 78. Assembled magnet.

Strain Gauges

A total of eight resistive strain gauges were installed on the aluminum cylinder. Six of them were located at the middle of the magnet. There are 4 azimuthal: 1A-a, 1B-a, 1D-a, 1E-a, and 2 longitudinal: 1G-l, 1H-l gauges. 1A-a and 1D-a were named as midplane-azimuthal gauges, and 1B-a and 1E-a as pole-azimuthal gauges with 90° difference in location on the cylinder. Gauges 1C and 1F were located on the edge to measure the average stress across the cylinder thickness.

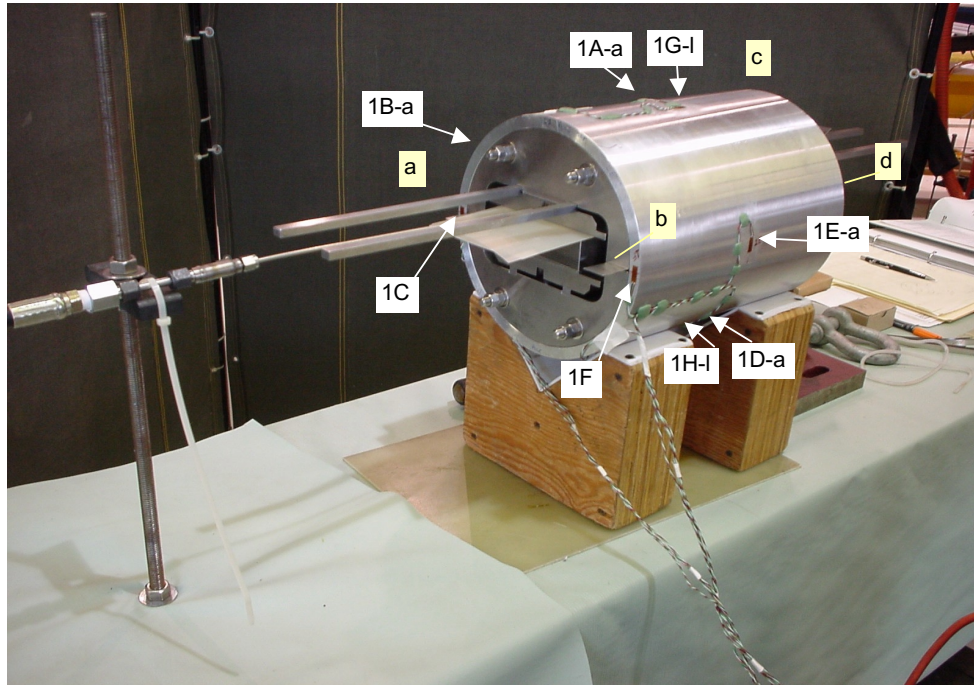


Figure 79. Strain gauges locations on the cylinder.

Gauge's data for the two assembly steps -cylinder-yoke pre-assembly and final assembly- are plotted in Fig. 80. Gauges 1A-a and 1D-a were chosen as main process indicators since they are located in the area of uniform cylinder stretching. The maximum load that was reached on the shell was 103 MPa. Spring back for the keying process is in the range of 25-30%.

All gauge parameters and the final readings are listed in Table 5. We also monitor an OD change for aluminum cylinder measured with Pi-tape and by micrometer. These data are plotted in Fig. 81.

Table 5. Final data of

Strain Gauges on the AL Skin of the SR-01 PIT FNAL

#	Strain Gauge Type		IB3 name	VMTF name	Gage Factor	Rzero	R(Fully-Loaded)-300K(IB3_final)
1	WK-13-250BG-350	Skin Gauges Azimuthal	1A-a	SG 1	2.07	349.999	350.834564
2	WK-13-250BG-350		1B-a	SG 2	2.07	350.492	350.081705
3	WK-13-250BG-350		1D-a	SG 3	2.07	350.2	350.864666
4	WK-13-250BG-350		1E-a	SG 4	2.07	350.312	349.9064
5	WK-13-250BG-350	Skin Gauges Longitudinal	1G-l	SG 5	2.07	350.113	350.039832
6	WK-13-250BG-350		1H-l	SG 6	2.07	349.771	349.658068
7	WK-13-250BG-350	Skin Gauges Cross-Section	1C	SG 7	2.07	350.273	350.673534
8	WK-13-250BG-350		1F	SG 8	2.07	350.36	350.760284
9	WK-13-250BG-350	Main Compensator	1l-comp	SGC	2.07	349.711311	349.711311

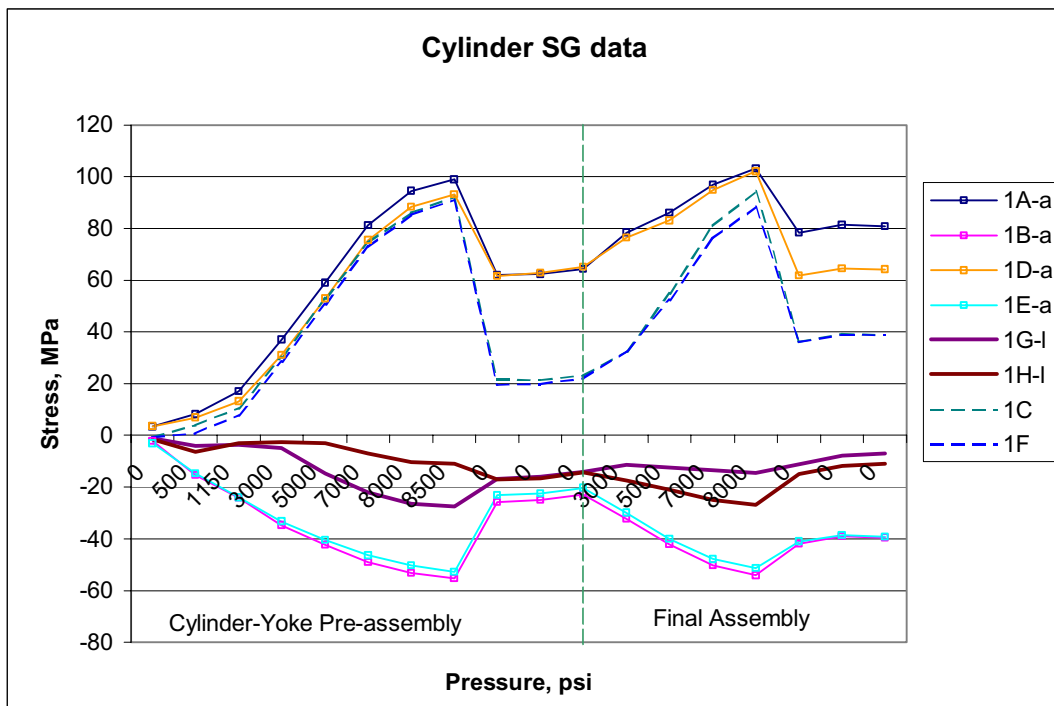


Figure 80. Strain gauges history.

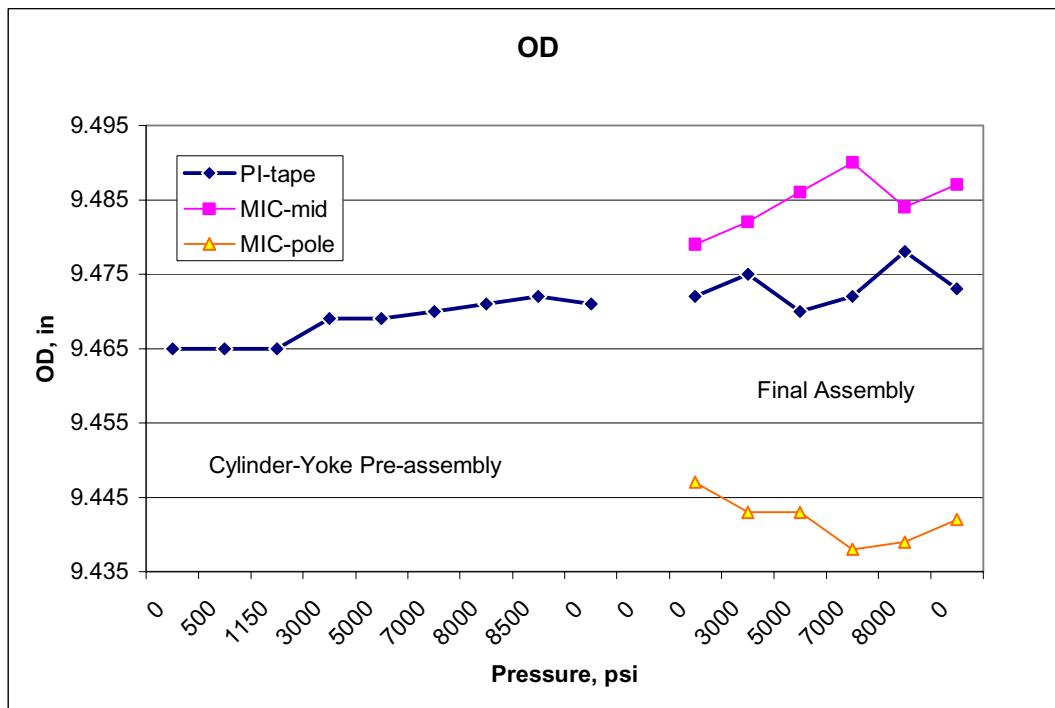


Figure 81. Cylinder's OD variations.

Electrical parameters

All electrical readings for coil L, R, Q are listed below for the various production steps:

Electrical test after winding of FNAL coil, PIT cable 11-11-03

		L	R	Q	F		
		uH	mV/.1A				
		22.0315	2.0612	2.42	1kHz		
		22.2187		0.08	20Hz		
11/11/2003	L	R	Q	F	L	R	Q
		s/f				s/f	
	21.221	1.9336	2.33	1kHz	21.567	1.945	2.48 1kHz
	21.583	2.0005	0.08	20Hz	21.282	2.043	0.08 20Hz

Electrical test after reaction before splicing of FNAL coil, PIT cable 12-09-03

L	R	Q	F
	1.9664		
15.201	1.9605	1.4	1kHz
18.857	1.9223	0.07	20Hz

Electrical test after reaction after splicing of FNAL coil, PIT cable 12-17-03

L	R	Q	F
uH	mV/.1A		
14.92	2.1071	1.88	1kHz
jumping	1.9769	jumping	20Hz

Electrical test before impregnation/fully assembled of FNAL coil, PIT cable 12-19-03

L	R	Q	F
uH	mV/.1A		
11.7217	2.112	1.52	1kHz
24.43		0.14	20Hz

Electrical test after impregnation/fully assembled of FNAL coil, PIT cable 12-22-03

L	R	Q	F
uH	mV/.1A		
11.3775	2.1072	1.5	1kHz
24.4		0.15	20Hz

Electrical test before yoking on bench assembled to go into yoke of FNAL coil, PIT cable 1-13-04

L	R	Q	F
uH	mV/.1A		
17.163	2.021	1.56	1kHz
35.324	1.9807	0.22	20Hz

Electrical test after removing bladders of FNAL coil, PIT cable 1-27-04

L	R	Q	F
uH	mV/.1A		
17.0509	2.0228	1.57	1kHz
36.7316		0.23	20Hz

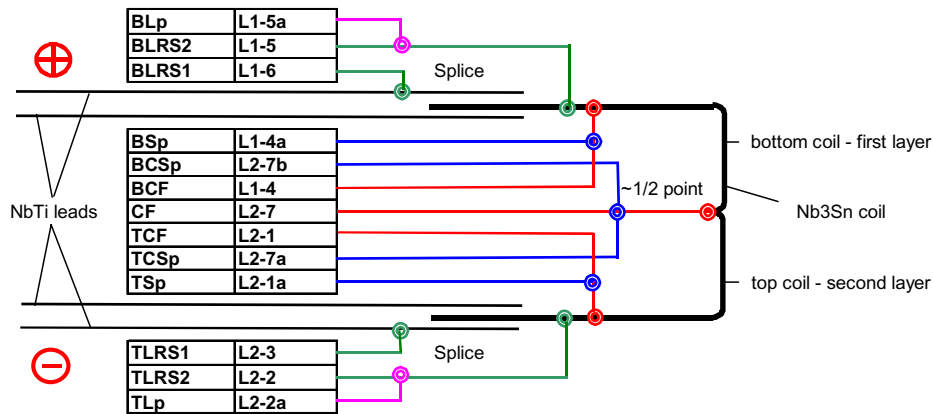
Electrical test final before ship to VMTF of FNAL coil, PIT cable 1-30-04

L	R	Q	F
uH	mV/.1A		
17.4013	2.1348	1.58	1kHz
35.1174	2.1051	0.21	20Hz

Voltage Taps

A total of 13 VT were attached to the coil. The VT connection scheme is shown in figure below.

All taps were attached to hypetronics according to document “VMTF Test Stand Magnet/DAQ System Interface. Magnet: SR01”.



VT reading at IB3

IB3		1/13/2004	1/27/2004	1/30/2004
L 2-3		1.95698	1.9702	1.9909
L 2-2		1.95641	1.9642	1.9921
L 2-2a			1.969	1.9966
L 2-1a (2-7b)			1.9683	1.9849
L 2-1		1.95431	1.9696	1.9859
L 2-7a (2-1a)			1.0136	1.0535
L 2-7		1.01091	1.0196	1.0432
L 2-7b			1.0063	1.0646
L 1-4		0.04712	0.0505	0.0902
L 1-4a			0.0524	0.0834
L 1-5a			0.0585	0.1081
L 1-5		0.04674	0.0546	0.1038
L 1-6		0.04698	0.0428	0.0911
Spot Heater	2.5564ohm	2.8ohm	3.0ohm	3.3ohm

	1/26/2004	V	A
Hi-Pot test			
coil-to-ground	1000V		<0.5 uA
SH-to coil	1000V		<0.5 uA
SH-to-ground	1000V		<0.5 uA

	1/30/2004	V	A
Hi-Pot test			
coil-to-ground	1000V		<0.5 uA
SH-to coil	1000V		<0.5 uA
SH-to-ground	1000V		<0.5 uA

#/position	Name/VMTF	Name/IB3	ΔI^*	Total*	Rforward	Dead/Alive	Location	Purpose	Twisted
1	BLRS1	L 1-6	0	0	0.0911	active	on the splice-NbTi cable lead-side	Quench Coil Lead Protection	
2	BLRS2	L 1-5	0.152	0.152	0.1038	active	on the splice-NbSn cable coil-side	Quench Coil Lead Protection	
3	BLp	L 1-5a	0	0.152	0.1081	active	on the splice-NbSn cable coil-side	Quench Current Lead Protection	along the NbTi lead
4	BSp	L 1-4a	0	0.152	0.0834	active	on the splice-NbSn cable coil-side	Spike Recording System	
5	BCF	L 1-4	0	0.152	0.0902	active	on the splice-NbSn cable coil-side	Quench Detection System	
6	BCSp	L 2-7b	6.848	7	1.0646	active	middle point	Spike Recording System	
7	CF	L 2-7	0	7	1.0432	active	middle point	Quench Detection System	
8	TCSp	L 2-7a (2-1a)	0	7	1.0535	active	middle point	Spike Recording System	
9	TCF	L 2-1	6.848	13.848	1.9859	active	on the splice-NbSn cable coil-side	Quench Detection System	
10	TSp	L 2-1a (2-7b)	0	13.848	1.9849	active	on the splice-NbSn cable coil-side	Spike Recording System	
11	TLp	L 2-2a	0	13.848	1.9966	active	on the splice-NbSn cable coil-side	Quench Current Lead Protection	along the NbTi lead
12	TLRS2	L 2-2	0	13.848	1.9921	active	on the splice-NbSn cable coil-side	Quench Coil Lead Protection	
13	TLRS1	L 2-3	0.152	14	1.9909	active	on the splice-NbTi cable lead-side	Quench Coil Lead Protection	

* estimation

Figure 82. Summary of VT's and Spot Heater's reading and Hi-pot test data.

Final Electrical Reading

Table 6. SR-01 final test.

Electrical test final before ship to VMTF of FNAL coil PIT cable 1-30-04

	R	L	Q	F
	mV/.1A	uH		
R-start	2.1348	17.4013	1.58	1kHz
R-finish	2.1051	35.1174	0.21	20Hz

VT reading at IB3

IB3	1/30/2004	
L 2-3	1.9909	
L 2-2	1.9921	
L 2-2a	1.9966	
L 2-1a (2-7b)	1.9849	
L 2-1	1.9859	
L 2-7a (2-1a)	1.0535	
L 2-7	1.0432	
L 2-7b	1.0646	
L 1-4	0.0902	
L 1-4a	0.0834	
L 1-5a	0.1081	
L 1-5	0.1038	
L 1-6	0.0911	
Spot Heater	3.3ohm	

Hi-Pot test	V	A
coil-to-ground	1000V	<0.5 uA
SH-to coil	1000V	<0.5 uA
SH-to-ground	1000V	<0.5 uA

Magnet Suspension

A nitrogen shield and set off G10 and stainless steel plates were attached to the magnet as part of suspension system to the cryostat. After securing the two magnet current leads and providing the necessary wiring, the magnet was shipped to VMTF.



Figures 83, 84. Magnet suspension with nitrogen shields and two NbTi leads.

References

- [1] E. Barzi, *Error analysis of short sample J_c measurements at the Short Sample Test Facility*, TD-98-055.